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ANALYSES FOR THE REQUIREMENTS FOR COMPUTER CONTROL AND DATA PROCESSING EXPERIMENT SUBSYSTEMS

EXPERIMENT CONTROL AND DATA PROCESSING REQUIREMENTS SPECIFICATION REPORT

MAY 15, 1970

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EXPERIMENT CONTROL

AND

DATA PROCESSING REQUIREMENTS

SPECIFICATION REPORT

May 15, 1970

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ABSTRACT

This document specifies the experiment control and data processing requirements of two candidate experiments for the NASA Manned Space Station. The primary apparatus and experiment protocol is presented for each experiment, and data processing hardware and software requirements for experiment automation are specified. This work was performed under contract number NAS8-25471 for the Computation Laboratory of the George C. Marshall Space Flight Center, Huntsville, Alabama.

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SECTION 1. INTRODUCTION

This document is the first of two reports required under NASA study contract number NAS8-25471, "Analyses of the Requirements for Computer Control and Data Processing Experiment Subsystems." The report was prepared by the System Development Corporation's Huntsville Space Projects staff for the Computer Systems Division of the George C. Marshall Space Flight Center's Computation Laboratory. The study is being performed in two phases. This report presents the results of the first phase, Phase A.

The objective of the Phase A effort was to perform a detailed study of selected space experiments and to specify their requirements for computer support. This approach provides specific requirements for a few selected experiments instead of an overview of computer requirements for the entire experiment subsystem. Phase A was performed in three major tasks:

- Task 1. Preliminary Definition
- Task 2. Detailed Analysis
- Task 3. Specification of Requirements

The Phase A results will be used as a baseline for the initiation of the Phase B effort, specification of the functional charactersitics of the Space Station data handling system design.

1.1 Task 1. Preliminary Definition

The performance of this task resulted in a baseline of information on experiments which typify the data processing requirements for Space Station experiment automation. The task was performed in three segments:

- A "Blue Book" Review, which provided a selection of experiments for the study baseline

- An Information Search which revealed the apparatus and operations involved in each of the selected experiments
- A Selection of Experiments to identify the two experiments best suited for the remaining efforts.

1.1.1 "Blue Book" Review

The study baseline for the Phase A effort was: "Candidate Experiment Program for Manned Space Stations--Draft" (NASA "Blue Book") dated September 15, 1969. Experiments are subdivided by discipline into 26 Functional Program Elements (FPE's). Each FPE was reviewed, placing particular emphasis on operations which could be automated.

As a result of the "Blue Book" review, the following FPE's were selected for detailed investigation:

5.1	Grazing Incidence X-Ray Telescope
5.7	Plasma Physics and Environmental Perturbation
5.8	Cosmic Ray Physics Laboratory
5.9	Small Vertebrates (Bio-D)
5.17	Contamination Measurements
5.20	Fluid Physics in Microgravity
5.21	Infrared Stellar Survey

1.1.2 Information Search

Each of the selected FPE's were researched to gain a better understanding of experiment design and operation, and to establish the level of availability of information which would be needed in the efforts to follow. The Redstone Scientific Information Center (RSIC) was the primary source of information. Other information was obtained through Mr. Bobby Hodges (COR), the Marshall Technical Library, the SDC technical library and a number of SDC consultants.

1.1.3 Selection of Experiments

Following the information search, two experiments were chosen from the selected FPE's. The criteria used for selection were:

1. There must be sufficient documentation and/or consulting services available.
2. The experiment must be of sufficient scope and duration to warrant automation.
3. Applications for computer support should be readily recognizable.
4. More than one scientific discipline should be represented by the experiments chosen.

Application of the above criteria resulted in the selection of the X-Ray Polarimeter experiment (FPE 5.1) and The Role of Gravity in Cardiovascular Function (FPE 5.9).

1.2 Task 2. Detailed Analysis

In this task the operational and physical characteristics of two experiments were defined in detail. In addition to the information sources employed in the Task 1 efforts, SDC in-house consultants possessing knowledge in the appropriate disciplines were called upon to assist in the experiment definition. Assistance was provided by Dr. Donald F. Mitchell in defining the biological experiment and Dr. Kwok M. Ong in defining the astronomy experiment. Several sources within NASA, in industry, and at the university level also contributed to the effort. (See Appendix A.)

The detailed definition of two space experiments first required that a general design concept of experiment related systems and subsystems be developed. This was accomplished by studying all available documentation on the selected experiments, and by making any assumptions about Space Station design which were required to complete the overall picture. The resulting design concept is presented in Section 2.

The definition of the detailed design and operational characteristics of two specific experiments required extensive research into their background, objectives, and scientific basis. The design of the experiment apparatus and the procedure for carrying out intended experiment operations were studied to reveal those experiment operations which would be enhanced by automatic data processing support.

1.3 Task 3. Specification of Requirements

The experiment operations to which techniques of automatic control and data processing could be applied beneficially were broken down into a number of hardware and software components. These components were then grouped into related categories and specified as requirements for data processing hardware and software support. The details of experiment design and operation, and the statement of both hardware and software requirements for experiment support are presented in Sections 3 and 4. The development of actual design specifications for the software requirements will be accomplished in Phase B of this contract.

SECTION 2. EXPERIMENT SUBSYSTEM CONCEPT

In order to explore details of experiment design, it was first necessary to understand the nature and general character of the facility within which the experiments must function. As a result of our studies, a general concept of the Space Station configuration was developed. This concept was based on available documentation. However, in order to complete the general design concept, some assumptions were made. Where this was done, care was taken to remain within the framework of design feasibility. The resulting Space Station configuration concept is discussed in the following sections:

- General Space Station Configuration
- Space Station Data Processing System

2.1 General Space Station Configuration

The overall Space Station configuration includes:

- The Space Station
- Free flying experiment modules
- Space shuttle support
- Communication network
- Ground experiment support

2.1.1 Space Station

A manned Space Station will be the heart of the Space Station system and will include:

- Environmental Control/Life Support (EC/LS) systems for crew members and living biological specimens
- Guidance, Navigation, and Control (GN&C) for both Space Station and free flying module supervision
- Communications with the ground, free flying modules, Space Shuttle, and inter-Space Station terminals

- Experiment facilities to support on-board experiments
- Logistics and maintenance support for the free flying modules.

2.1.2 Free Flying Experiment Modules

Free flying modules will be used for experiments requiring near-zero vibration and a contamination free environment. They will contain:

- A propulsion system for maintaining the requisite position with respect to the Space Station, celestial sphere, and orbital path
- Pointing and tracking ability to acquire and automatically track desired targets
- Communication facilities and the automatic/remote control capabilities required to carry out planned operations
- Rendezvous and docking facilities for maintenance and resupply.

2.1.3 Space Shuttle Support

Shuttle service between the ground and the Space Station is required to provide the following logistics support:

- Experiment equipment and personnel
- Experiment consumables
- Return of experiment data (film, tape, specimens, etc.)

2.1.4 Communication Support

The following communication services will be provided for Space Station support:

- Ground communication (at least once per orbit)
- Shuttle communication (as required)
- Free flying module communication (continuously)
- Inter-Space Station communication (continuously)

2.1.5 Ground Experiment Support

Principal investigators who remain on the ground must be provided the following:

- Experiment monitoring and "quick look" capability
- Overall experiment control
- A means for consulting with the on-board experimenter on experiment related matters

2.2 Space Station Data Processing System

Figure 2-1 depicts the general concept for a Space Station Data Processing System. Only those parts of the system that are involved directly with experiment automation or are interfaced with the experiment subsystem will be defined. Major subsystems which will be discussed include:

- Experiment subsystem
- Guidance, Navigation and Control subsystem
- Communication subsystem
- Command and Control subsystem

2.2.1 Experiment Subsystem

Since the nature of the Space Station program is experimental investigation, the bulk of the on-board data processing and handling will be experiment related; therefore, the experiment subsystem will require a dedicated computer. This concept permits the development of data processing requirements for experiment support which are independent of other on-board data processing operations and which impose minimum constraints on the overall system design.

The work load of the experiment subsystem includes the following experiment functions:

- Retrieving, formatting, processing, and interpreting data from primary instruments
- Monitoring of secondary or support instruments

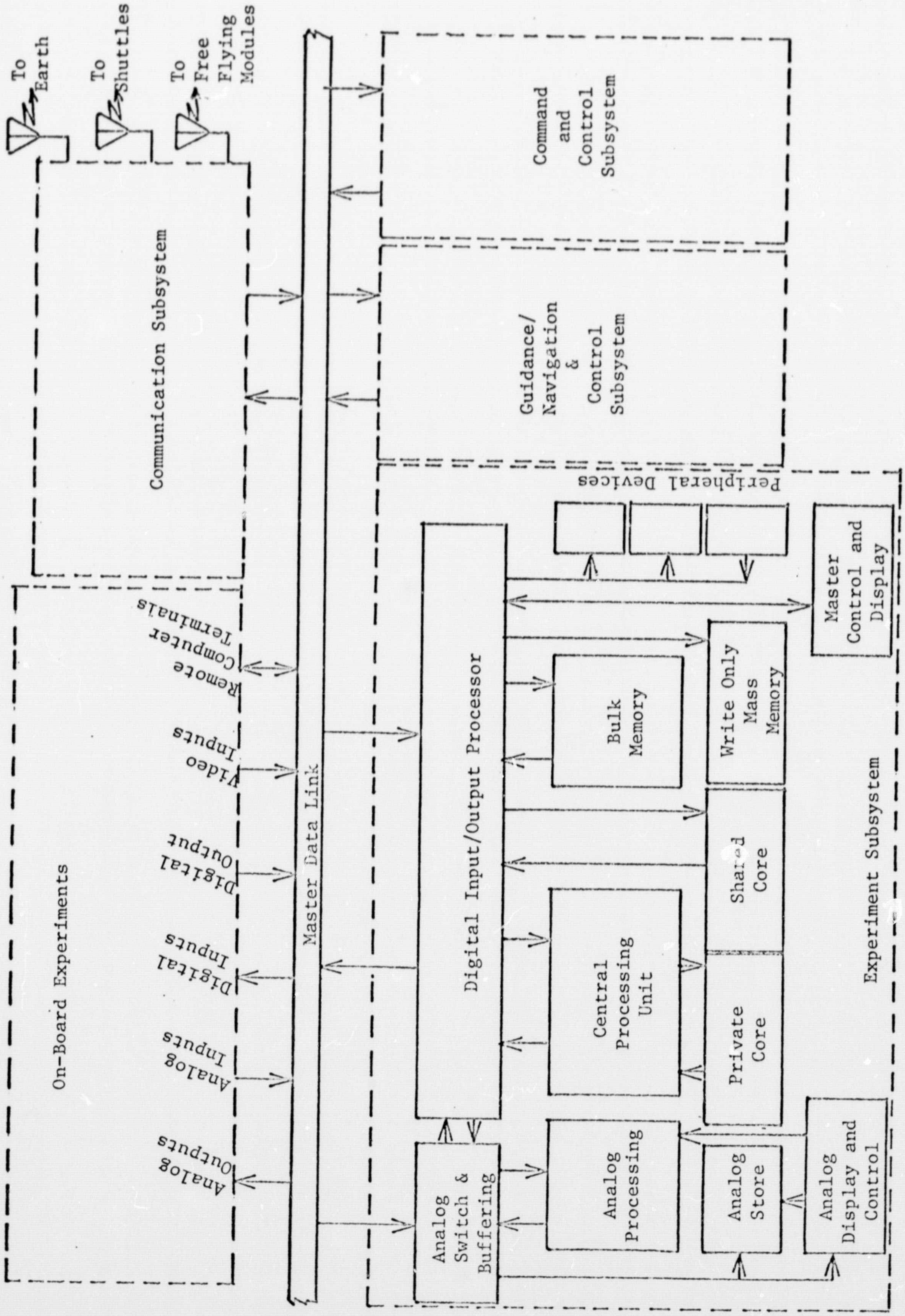


Figure 2-1. Experiment Data Processing System

- Control of instruments
- Control of experiment processes
- Coordination of multiple experiments with other subsystem functions
- Data elimination and compression
- Data storage
- Information display

The basic experiment subsystem (see Figure 2-1) includes the following hardware items:

- A central processor capable of controlling multiple experiments
- A large high speed memory for program and current data storage
- A very large bulk data store for temporary storage of digital and analog data
- Massive write-only storage for permanent data records
- A high speed I/O capable of handling all requisite data transactions
- Experimenter terminals
- Other peripherals necessary to support experiment requirements.

2.2.2 Interfacing Subsystems

All subsystems which interface with the experiment subsystem will be capable of operating independently of each other within their assigned area of control. These subsystems include:

- A Guidance, Navigation and Control subsystem which maintains the Space Station in the desired orbital position and attitude; monitors and controls the attitude and pointing of all free flying modules; and controls rendezvous and docking of free flying modules and the shuttle
- A communication subsystem which controls and schedules all inter- and intra-Space Station data transmission; performs data compression; stores data for delayed transmission; controls data dumps to ground stations; and communicates with free flying modules and the shuttle

- A command and control subsystem which maintains control of the entire Space Station complex; handles logistics; monitors and controls all EC/LS functions; provides emergency detection, damage control and containment services; and schedules and monitors interaction and interdependencies of all other subsystems.

SECTION 3. X-RAY POLARIMETER EXPERIMENT (FPE 5.1)

In the eight years since its beginning, X-ray astronomy has come to be regarded as the most important development in the history of space astronomy. Over forty objects have been observed for which X-ray emission is one of the most important forms of energy emission.[1] Various characteristics of the X-radiation emitted by these sources are of particular scientific interest. For example, an object in the Crab Nebula has been identified as a pulsar in the radio, optical, and X-ray wavelengths. X-ray observations of this and other pulsating sources may lead to a clearer understanding of the origin of pulsars.[2] In addition, the determination of any polarization effects of stellar X-ray sources is an important clue to the origin of these sources.[3]

At present, only a few X-ray sources have been associated with optical or radio counterparts.[4] This is due to the poor resolution of the instruments used for observation, and the short duration of sounding rocket and balloon flights. Also, with high altitude balloons, observations are limited to the energy range above 25 keV because of the high level of atmospheric background radiation. Therefore, satellite borne telescopes are a fundamental requirement of X-ray astronomy.[5]

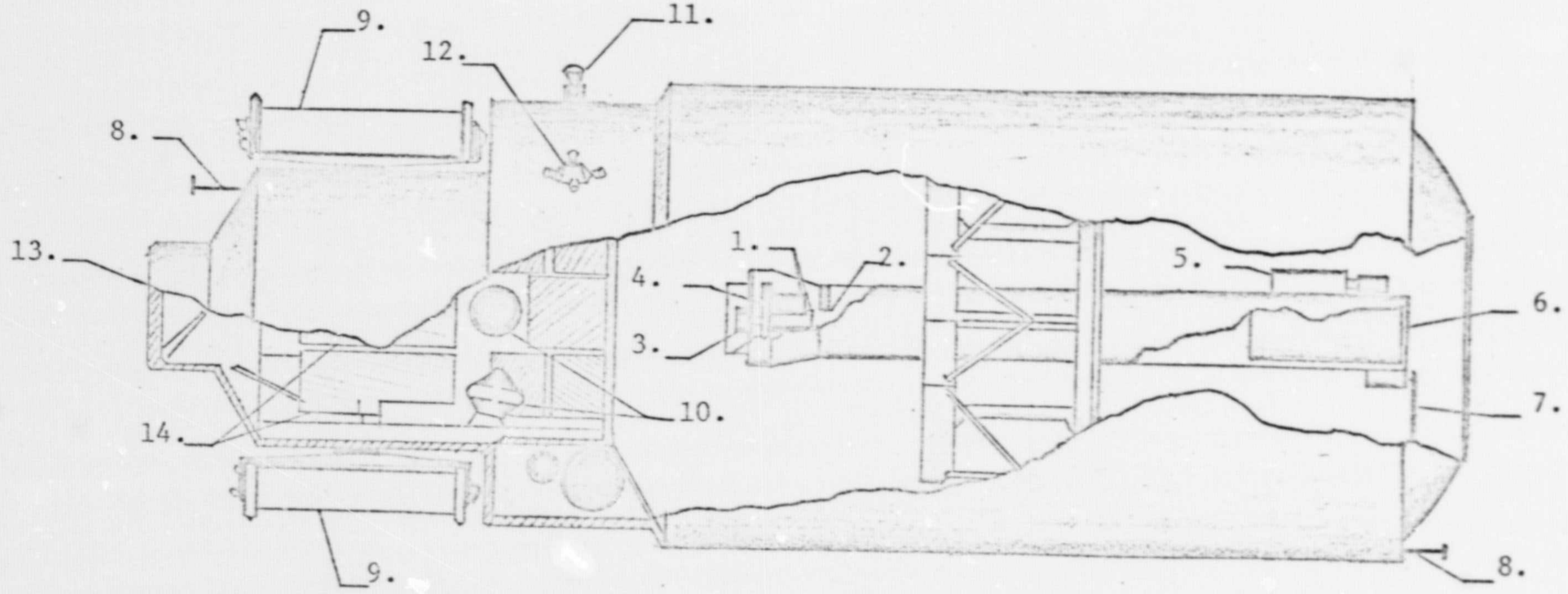
By the mid-1970 time period of this experiment, a number of satellite borne experiments in the field of high energy astronomy will have been carried out. The Advanced Apollo program will have conducted numerous experiments and the initial flights of the High Energy Astronomical Observatory will have scanned the galactic and celestial fields for sources of high energy emission.[6] Therefore, the X-ray astronomy module will be flown under much more enlightened circumstances than would be possible today. Major X-ray sources will be well known and fairly accurate data on their intensity will be available.[7] Such information can be used to configure experiment operation to optimize experiment results.

3.1 Experiment Description

The X-ray polarimeter experiment assembly consists of the optics and instrumentation necessary to determine the degree of polarization of X-ray sources in the energy region between 1 and 4 keV (12.4 and 3.1 angstroms). Basically, the experiment consists of a large grazing incidence X-ray telescope (see Figure 3-1) which is used to focus incident X-radiation onto various instruments located in the telescope focal point. The various instruments will be mounted on a turret which can position each device at the focal point as needed. In this experiment, an X-ray polarimeter is positioned at the focal point to make observations of X-ray objects of interest. These objects are acquired and tracked for the time necessary to record significant data and the telescope is then moved to the next object. It is recognized that another approach would be to swivel several of the various X-ray sensing devices into position for each object before moving on to the next target; however, since this experiment is designed primarily for the purpose of determining X-ray polarity, the more straightforward sequence is assumed.[8]

Due to requirements for minimal vibration and environmental contamination, this experiment is housed in an unmanned, free flying astronomy module which is supported and controlled by the Space Station.[9] In addition to the basic equipment apparatus, the astronomy module will include the following support systems:

- A pointing and control system consisting of strap-down rate gyros for space reference, two star trackers for reference update, and a set of control moment gyros (CMG) for positional torqueing. The same reaction control system (RCS) is used for CMG desaturation as is used for docking, undocking and other limited orbital maneuvers. The pointing and control system is controlled by an on-board digital computer which receives target acquisition and tracking commands from the Space Station GN&C system.



Principle Components are: 1. Experiment Instruments, 2. Focal Point Aperture, 3. Experiment Turret Motor, 4. Experiment Turret, 5. Aspect Camera, 6. Grazing Incidence X-Ray Mirror, 7. Aperture Disc, 8. Communications Antennas, 9. Solar Cell Arrays (Stowed), 10. Control Moment Gyros, 11. Star Tracker, 12. Reaction Control Nozzles, 13. Docking Hatch, 14. Fxperiment and Module Electronics

Figure 3-1. X-Ray Telescope Astronomy Module (Free Flying)

- A data handling system capable of receiving and executing commands from the Space Station and controlling and transmitting data to the Space Station (see Figure 3-2).[10] No direct communication between the astronomy module and the ground is assumed; however, periodic communication between ground based controllers and the Space Station will be necessary for overall direction and monitoring of the experiment.[11]

3.1.1 Primary Instruments

The primary instruments which are vital to the success of this experiment are:

- A large collecting area grazing incidence telescope
- An instrument turret assembly
- An X-ray polarimeter
- A polarimeter rotation table
- An aperture disc
- A boresighted aspect system
- A set of proportional counters
- Associated counting, control and data handling electronics

3.1.1.1 Grazing Incidence Telescope. The grazing incidence telescope works on the principle of external reflection at the boundary between two substances. An application of Fresnel's equations defines a critical angle less than which an incident X-ray is totally reflected. By constructing a surface in the form of several superimposed, truncated paraboloid/hyperboloid mirrors (see Figure 3-3), it is possible to obtain X-ray collection efficiencies in the soft X-ray region (2-2000 angstroms) of better than 10 per cent.[12]

3.1.1.2 Instrument Turret. The instrument turret is used to position one of several sensing devices at the focal point of the X-ray telescope.[13]

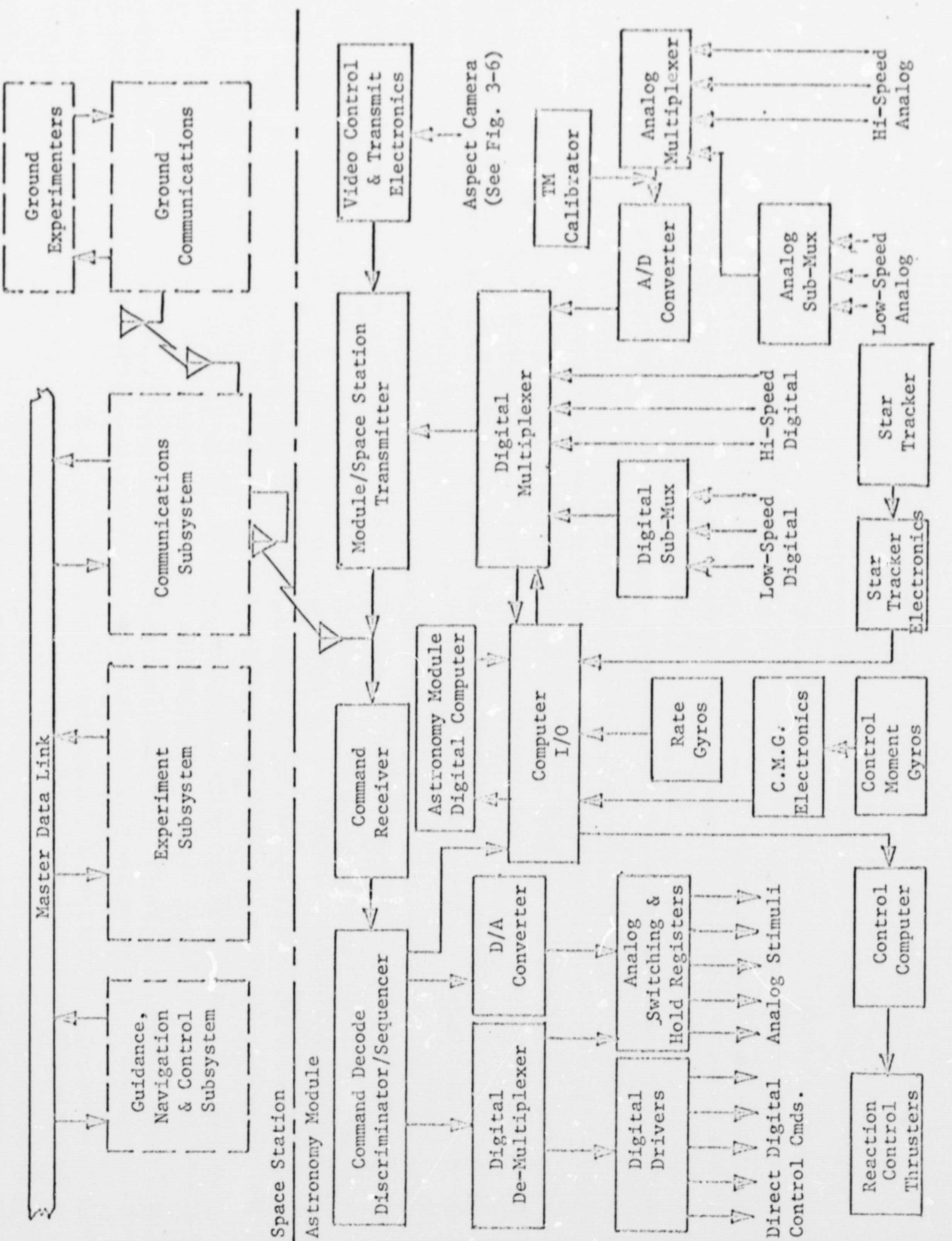


Figure 3-2. Astronomy Module Data Handling System

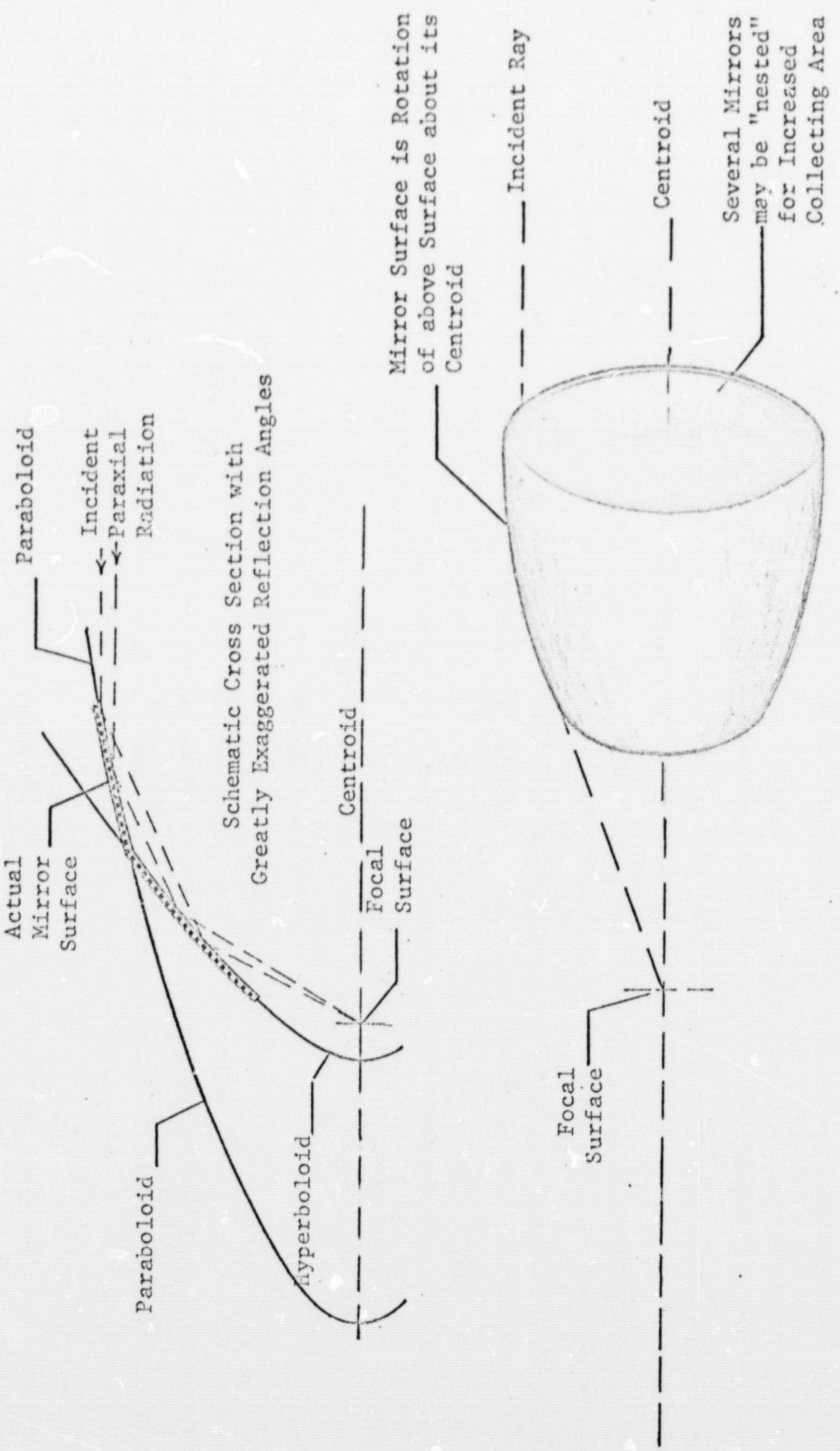


Figure 3-3. Grazing Incidence X-Ray Mirror

3.1.1.3 X-Ray Polarimeter. In the X-ray polarimeter, X-rays at the focal point of the telescope strike a thin crystal which is situated at an angle of 45° to the X-ray beam (see Figure 3-4). The chosen crystal exhibits a crystalline structure of cubic symmetry and will tend to reflect X-rays in the energy range of approximately 2.6 keV at an angle 90° to the incident beam. This reflection will have a maximum value when the plane of polarization of the incident X-ray is perpendicular to the plane described by the vectors of the incident ray, the reflected ray, and the normal to the crystal surface at the point of incidence.[14] Since the crystal is very thin and the coefficient of maximum reflectivity relatively small, several crystals are placed in series to reflect a significant amount of radiation (see Figure 3-5).

3.1.1.4 Rotation Table. The table, which is capable of being rotated by a stepping motor, is used to rotate the polarimeter about the center axis of the telescope. This varies the angle between the plane of polarization and the plane in which rays will be reflected and thus allows the determination of the angle of polarization of the ray.

3.1.1.5 Aperture Disc. The aperture disc at the front end of the telescope is used to partially occult emission of very high intensity.

3.1.1.6 Aspect System. The aspect system, a high sensitivity vidicon, boresighted to the telescope longitudinal axis, provides a visible record of telescope pointing and a means of verifying target acquisition.

3.1.1.7 Proportional Counters. A proportional counter is placed in the path of the reflected rays and the entire assembly rotated around the telescope axis to measure the reflection as a function of the angle. A second proportional counter is placed behind the crystals to measure the radiation which passes through without being reflected. The proportional counters have associated anti-coincidence counters for detection of high energy radiation outside of the X-ray spectrum.[15]

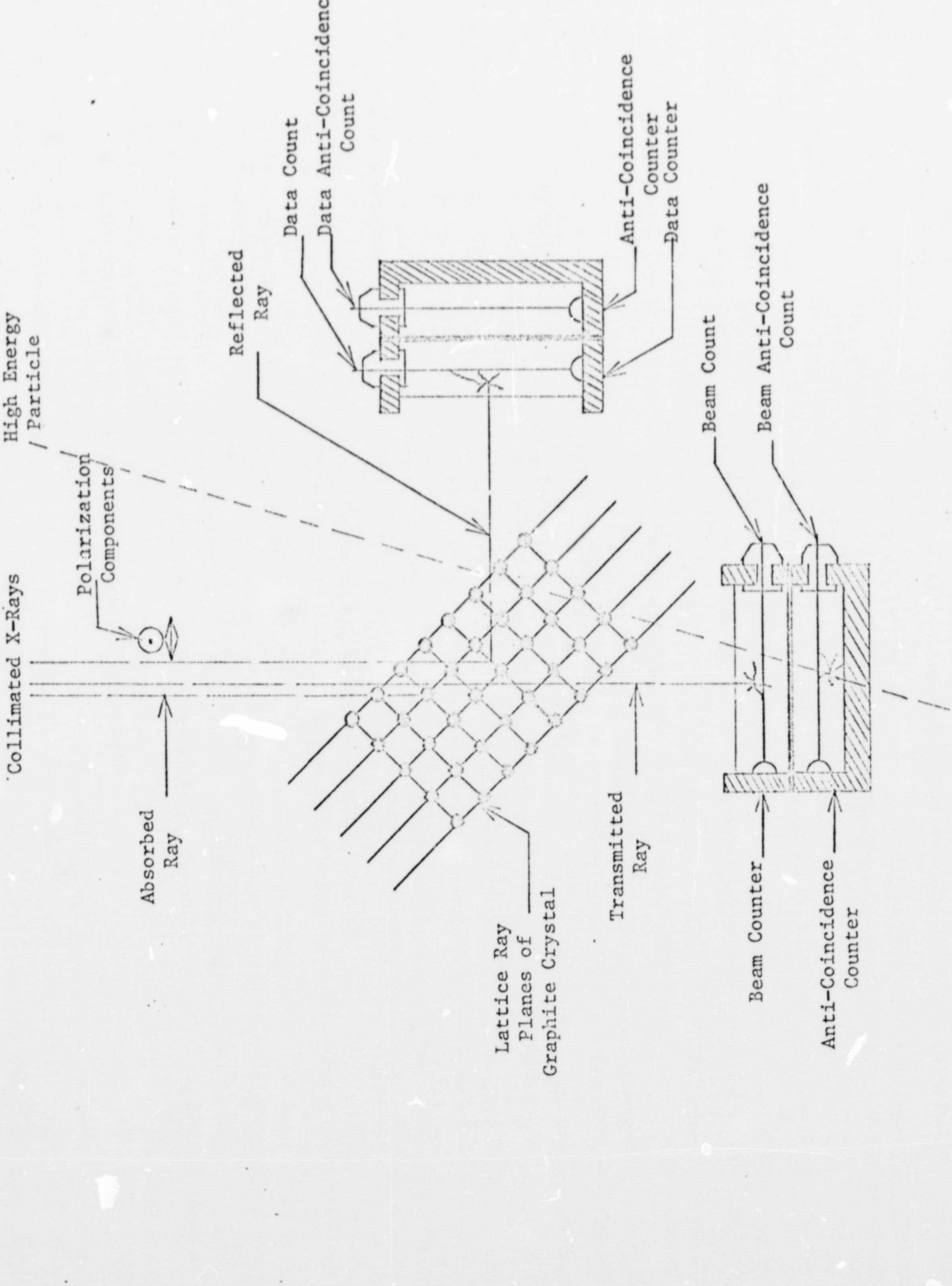
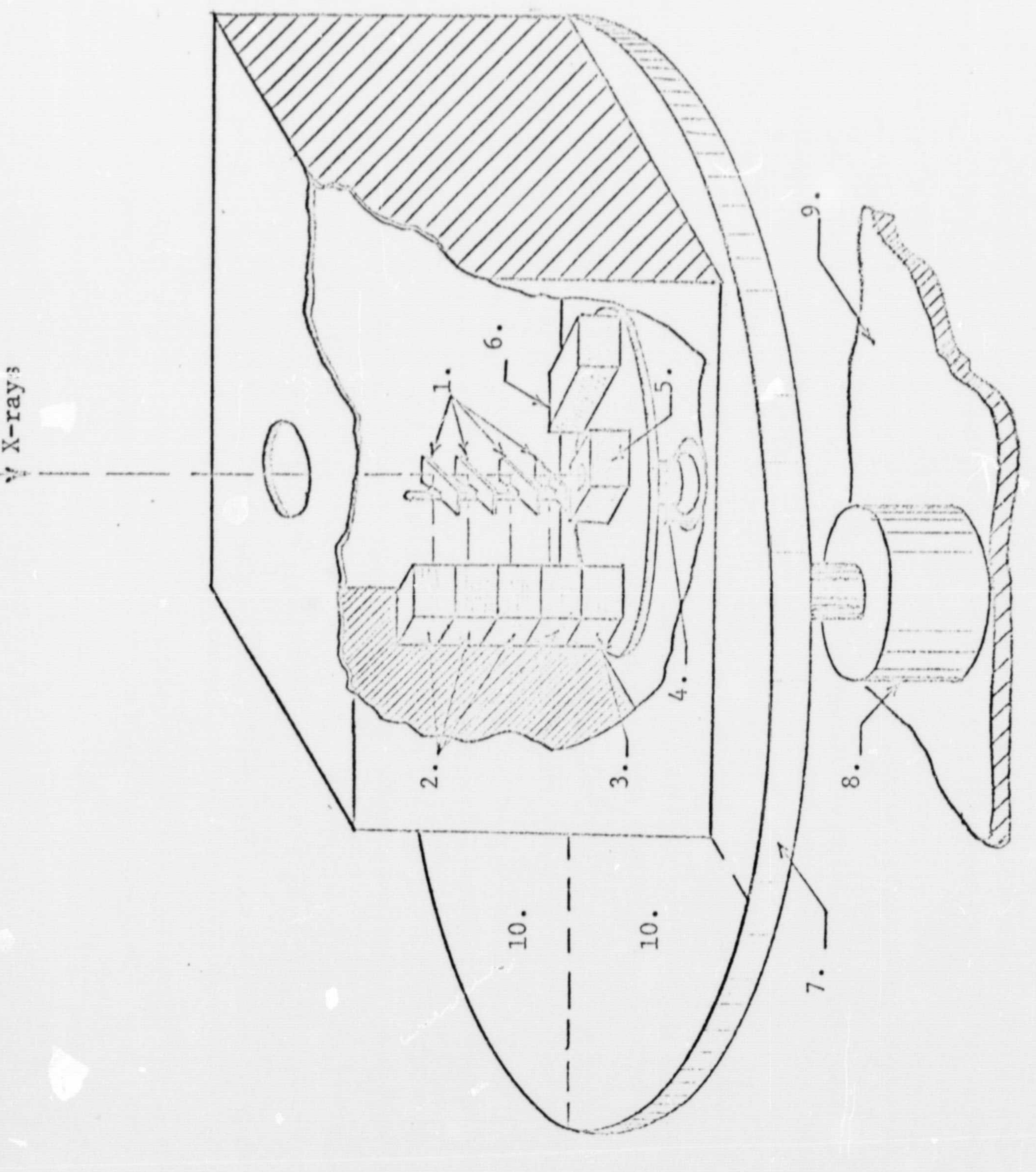


Figure 3-4. Graphite Polarimeter Concept



Principle Components are: 1. Graphite Crystals, 2. Data Proportional Counters, 3. Counter Pre-Amps, 4. Stepping Motor, 5. Beam Monitor Counter, 6. Counter Power Supplies, 7. Instrument Turret, 8. Turret Motor, 9. Telescope Frame, 10. Space for Additional Instruments

Figure 3-5. X-Ray Polarimeter Instrumentation

3.1.1.8 Data Handling Electronics. The electronics associated with the polarimeter are depicted in Figure 3-6 and described in the following paragraph.

The proportional counter outputs are fed into amplifiers and then into pulse shape discriminators which determine from the rise time characteristics of the pulse whether or not the signal is of an X-ray origin. The outputs of the anti-coincidence counters are fed into logic circuits which reject simultaneously occurring counter and anti-coincidence pulses. Since the anti-coincidence counters will only respond to radiation of a higher energy than is of interest in this study, the combination of pulse shape discrimination and anti-coincidence rejection effectively limits the resulting count to X-ray emissions of the desired energy level. The pulsar mode detector is included in the electronics package to indicate whether or not count was received during the past one-millisecond time slot. The binary counters (scalers) are provided to collect a number of counts and reduce the requirement to continuously scan the counters. The instrument sequencer controls the overall operation of the electronics package, and the control and data buffer serves as the interface device between experiment instrumentation and the astronomy module communications link.[16]

3.1.2 Secondary Instruments

The major portion of the instrumentation on board a free flying astronomy module will be devoted to making those measurements commonly referred to as engineering or "housekeeping" measurements. The following list, taken from the instrumentation system for the Apollo Telescope Mount (ATM), illustrates the nature and number of those measurements which support the experiment packages, and those which are associated with other ATM functions.[17]

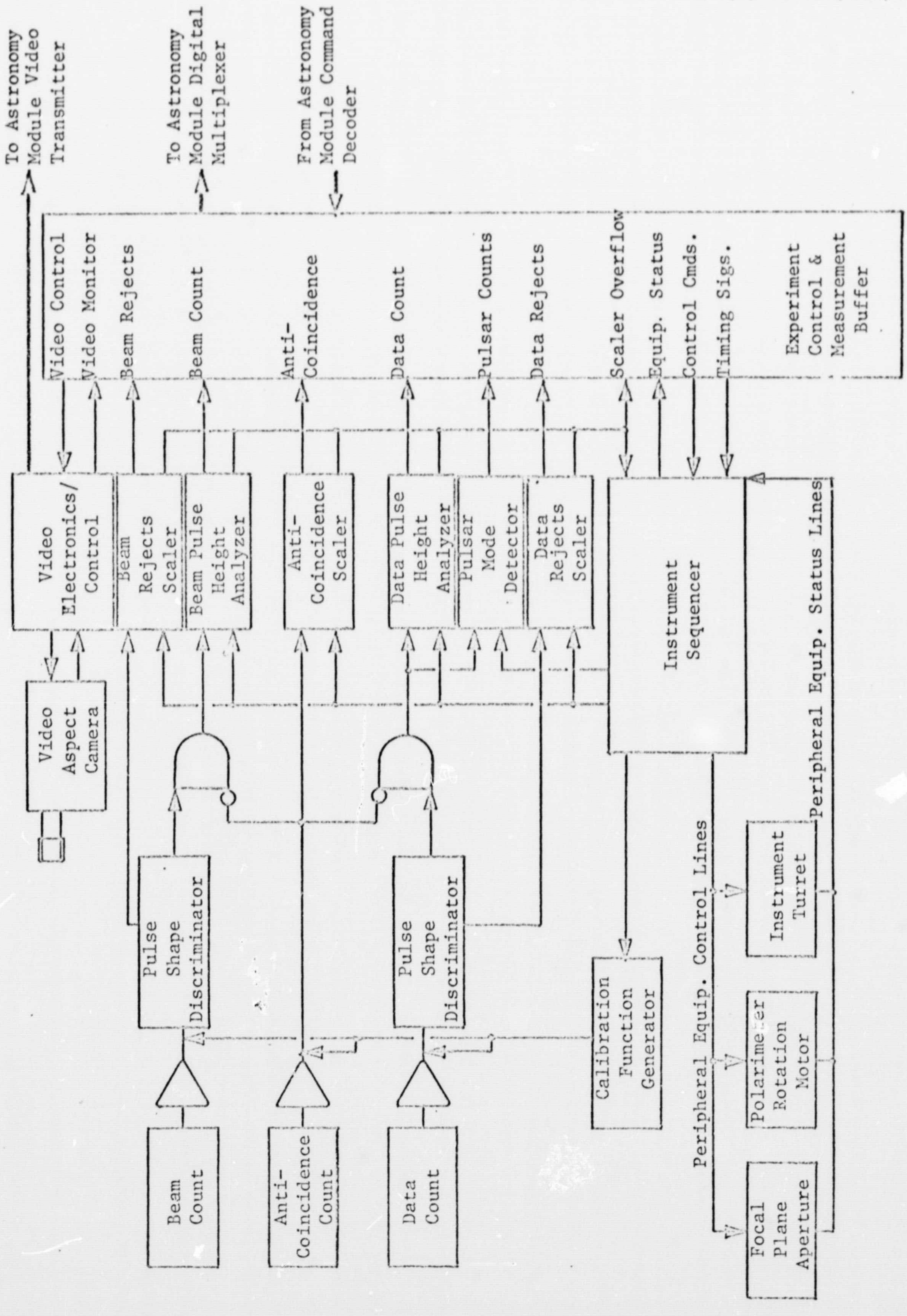


Figure 3-6. X-Ray Experiment Data Handling Electronics

	# Channels Supporting Engineering Operations	# Channels Supporting Experiment Operations
Temperature	182	122
Pressure	22	0
Distance	9	2
Events	219*	65*
Quantity	5	0
Electricity	189	98
Velocity (Angular)	11	0
Speed	4	0
Total	641	287

*Submultiplexed channels may provide multiple inputs for each of these measurement channels.

To provide a similar secondary instrumentation capability, the X-ray astronomy module must contain the following:[18]

- Electrical transducers which provide an electrical indication of such module parameters as accelerations, temperatures, pressures, voltages, etc.
- Signal conditioners to amplify and provide a standard signal level output to the data acquisition system
- Electrical wiring within the module to route the conditioned outputs to the on-board data multiplexers
- A digital data acquisition system which consists of such multiplexers, submultiplexers, buffers, and control devices as are needed to generate pulse code modulation (PCM) for transmission to the Space Station
- Such radio frequency (RF) components as transmitters, couplers, antennas, etc. as required to transmit the PCM data to the Space Station

- PCM receiving equipment on the Space Station which can receive, demodulate, and buffer the astronomy module signal to provide access by on-board subsystems (including the experiment subsystem) and ground observers (through the Space Station to ground link).

3.2 Experiment Operations

The Operating Procedure Flow Diagram (Figure 3-7) depicts the operations performed during a normal experiment observation sequence. This flow is presented as a typical series of operations to illustrate the sequence of events in a prescheduled operations plan, and is not intended to reflect the many possible operations which might be performed at the discretion of the experimenter. The procedure is independent of any automation system that may be employed. However, it is assumed that for these operations the sequence begins with the astronomy module in position relative to the Space Station, and with all attitude control, power, and data handling systems active. Real-time control and monitoring is maintained on board the Space Station by the on-board experimenter, and overall experiment control is exercised from the earth by the principal investigator.

The following discussion provides details on each activity of the Operating Procedures Flow Diagram:

- Calibrate Telemetry: Astronomy module telemetry should be calibrated periodically during the operations. This is necessary to provide a high level of confidence in the resultant data and to provide calibration benchmarks for use in telemetry data reduction.

- Power-Up and Initialize Experiment: Power application to the experiment apparatus must be accomplished in a step-by-step fashion, verifying the proper completion of each step before the next is taken.

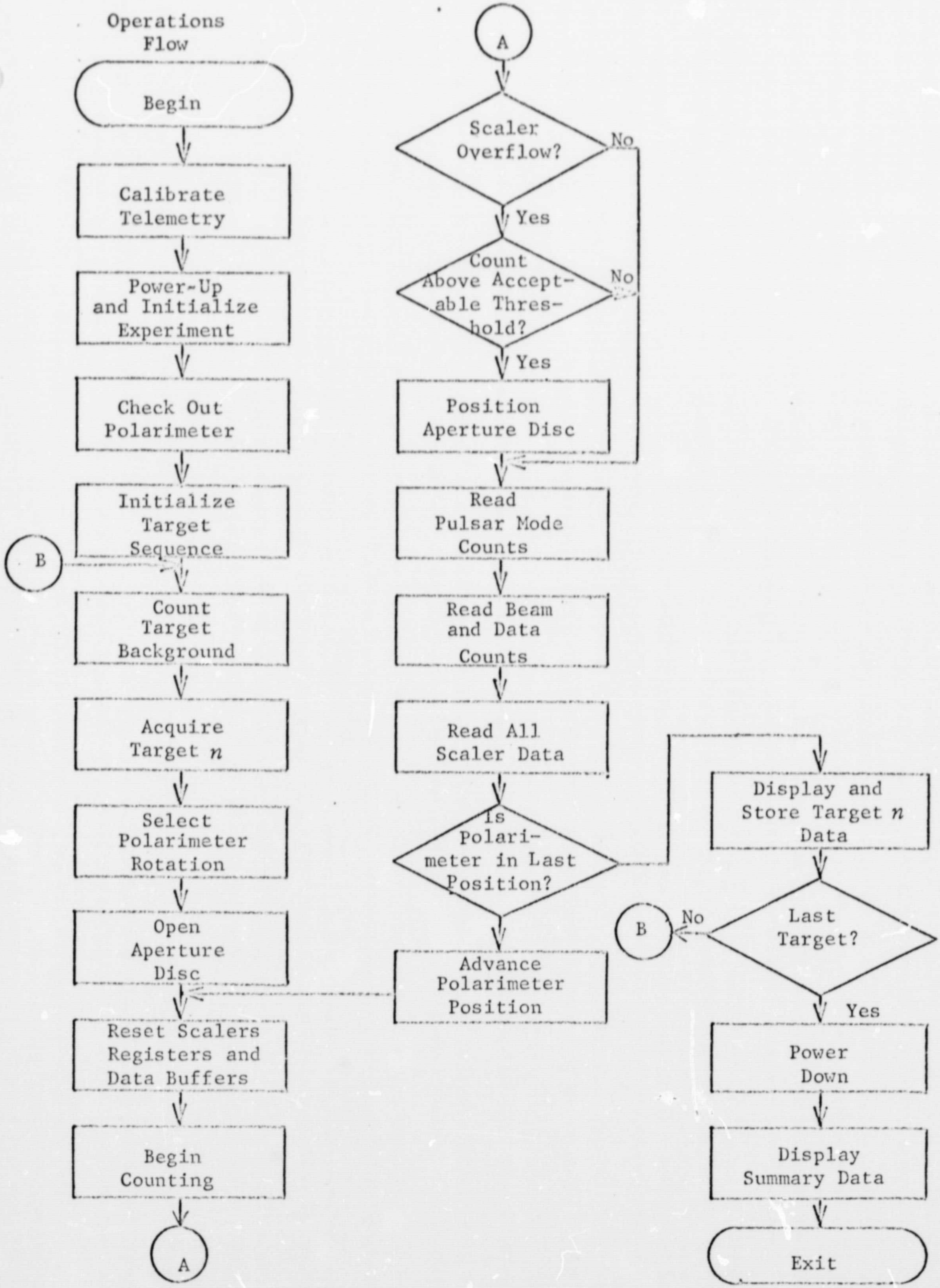


Figure 3-7. Operating Procedure Flow Diagram

- Checkout Polarimeter: An active checkout of the polarimeter apparatus must be performed either as an integral part of the power-up sequence or after all power is applied. A function generator is used to check all experiment electronics except the proportional counters. A short scan of certain well known celestial X-ray sources will provide an adequate counter verification.

- Initialize Target Sequence: A list of targets and the order in which they are to be studied is prepared in advance of the experiment operation. In carrying out a normal observation sequence, the targets are scanned in the order indicated.

- Count Target Background: The X-ray background will affect the data study of a discrete X-ray source by adding to the total count. By noting the level of this background, compensation can be made in the data. Also, since the background count can provide valuable information about the level and wavelength of absorption by the interstellar media, it is an important clue to the density and composition of that media.[19]

- Acquire Target: Target acquisition is accomplished automatically by the astronomy module pointing and control system on command from the Space Station. The Space Station observer accomplishes target verification by comparing aspect camera images with reference star fields.

- Select Polarimeter Rotation: The degree and rate of polarimeter rotation is specified by the principal investigator for each target. This information is stored along with other data in the target sequence list.

- Open Aperture Disc: Since the aperture disc partially occults X-ray emission, this operation assures that the disc is removed before observations of a target begin.

- Reset Scalers Registers and Data Buffers: Binary registers provide a running total of proportional counter outputs. This operation resets these registers in preparation for a new counting sequence.
- Begin Counting: This operation simultaneously opens the input gates to all of the binary registers to begin taking data.
- Scaler Overflow: Scaler overflow occurs when all bits in a binary register read "1" and another pulse is applied to the input.
- Count Above Acceptable Threshold: Very intense X-ray sources may tend to saturate the data handling capability of the experiment. This may be signified by a number of scaler overflows occurring in a specified period of time.
- Position Aperture Disc: This operation will result in a calculated reduction in counting rate.
- Read Pulsar Mode Data: The binary string which is the output of the pulsar mode counter is continuously scanned to reveal any source pulsations.
- Read Beam and Data Counts: Proportional counter outputs are sorted by pulse height analyzers into one of eight height levels and stored in appropriate binary buffers. These buffers are read to determine the number of counts and their approximate amplitude.[20]
- Read All Scaler Data: High energy radiation such as gamma rays or heavy particle counts are signified by counts from the anti-coincidence circuitry or from the pulse shape discriminators. Binary scalers store these counts and are read to determine count rejects.[21]
- Is Polarimeter in Last Position: The polarimeter table is rotated by applying pulses to a stepping motor. The number of steps and, hence, the degree of rotation is included in the target sequence list.[22]
- Advance Polarimeter Position: This rotates the polarimeter table one step.

- Display and Store Target Data: Target data is automatically provided in preprocessed form to the Space Station observer and to ground personnel, and is stored for later analysis. "Raw" data is available upon request.

- Last Target: Operations are terminated when observations of the last target on the target list are complete.

- Power-Down: Power is automatically removed from the experiment apparatus in accordance with a pre-established procedure.

- Display Summary Data: Overall summary data will be provided in tabular and graphic form to supply "quick look" information on the results of the data sequence and to summarize the performance of on-board systems during the sequence.

A number of operations must be performed aboard the astronomy module which are of a routine nature. Periodic monitoring of secondary instrumentation such as voltage, temperature, pressure, etc., will be controlled by the experiment subsystem.

3.3 Selection of Operations for Computer Support

Each of the above operations is a potential candidate for automation. Each was reviewed to determine the feasibility of computer support, and those operations for which such support is required are described as follows:

- Astronomy module telemetry calibration should be accomplished automatically under control of the experiment subsystem.

- Such routine, repetitive sequences as power-up, power-down, and equipment status checks, etc., should be automated and capable of call-up by manual request or as a part of an automatic call-up.

- Emergency routines should be provided which can place the experiment apparatus in a passive condition with a minimum time delay.

- Equipment checkout routines of a variety of levels of complexity should be automated.

- A means should be provided to automatically coordinate target pointing operations so that a list of targets can be observed in the order which best compliments the experiment data taking plan. The capability to enter such a target list in standard celestial coordinates is required.

- Automatic primary instrument operation should be provided to a level which will provide the experimenter a flexible tool for carrying out "hands-off" data taking sequences.

- All primary data should be automatically collected, sorted, and stored in retrievable memory along with such background and secondary data as may be required for the generation of displays, future reference on the ground or in space, or for inclusion in more complex data processing operations.

- Displays of source polarization, intensity, pulsation frequency and other pre-specified information should be automatically provided on demand.

- The ability for on-demand call-up of specific experiment data is required for both ground and space observation. The ability to assign high/low alarm limits to specific measurements should also be provided.

3.4 Software Requirements

This section presents the software requirements for the operations selected for automation in the previous section. The software design for the X-ray polarimeter experiment is presented in Figure 3-8. This block diagram presents the major routines required to automate this experiment. Requirements for each major routine are presented in Sections 3.4.1 through 3.4.13.

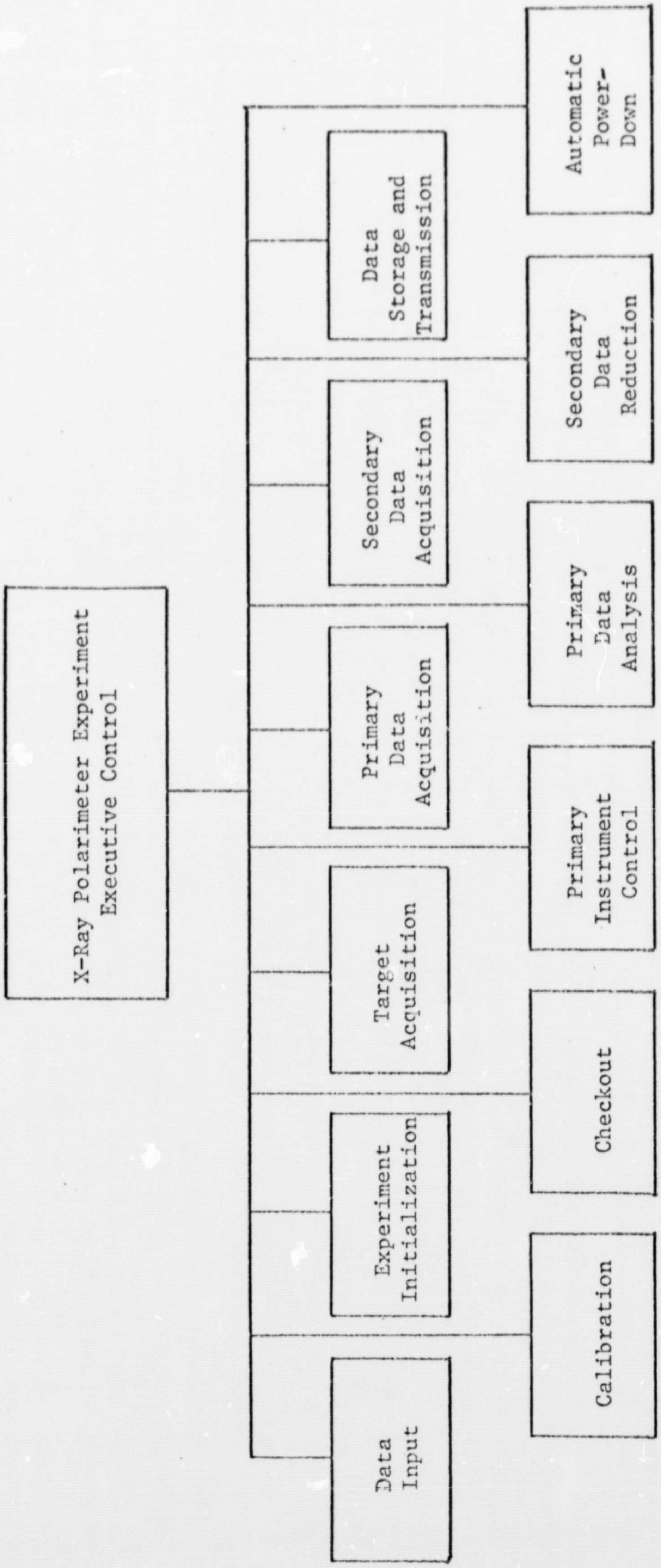


Figure 3-8. Software Design for X-Ray Polarimeter Experiment

3.4.1 Experiment Executive

An executive routine is required to perform overall control of the experiment procedure. This rou[illegible] must initiate and verify execution of all preliminary experiment operations [illegible]luding data input, calibration, power-up and checkout and must control the sequencing and timing of all experiment data taking operations including target acquisition, instrument control, and the acquisition, analysis, reduction, storage, transmission and display of data.

3.4.2 Data Input

The Data Input routine is required to load X-ray polarimeter experiment data into the system (see Figure 3-9).

The Data Input routine must accept, and store in table format, a list of targets to be observed. This target list must specify the sequence of observations, optimum observation time, observation duration, target coordinates and all other parameters necessary to acquire targets of interest and obtain data from them.

The Data Input routine must accept a list of secondary instruments to be monitored during the experiment sequence. This list will provide the measurement address, type of measurement, sampling frequency, tolerances, etc. This routine must also be able to update the Equipment Status Table and the Master Checkout Table by accepting additions, modifications or deletions to these tables. For a particular sequence of observations, this routine must input and store all variable data which are not included in the target or secondary instrument list.

The Data Input routine must be capable of performing on-line updates during experiment operation due to experiment redirection or anomalies which may effect the sequence of target acquisition, timing of observations, etc.

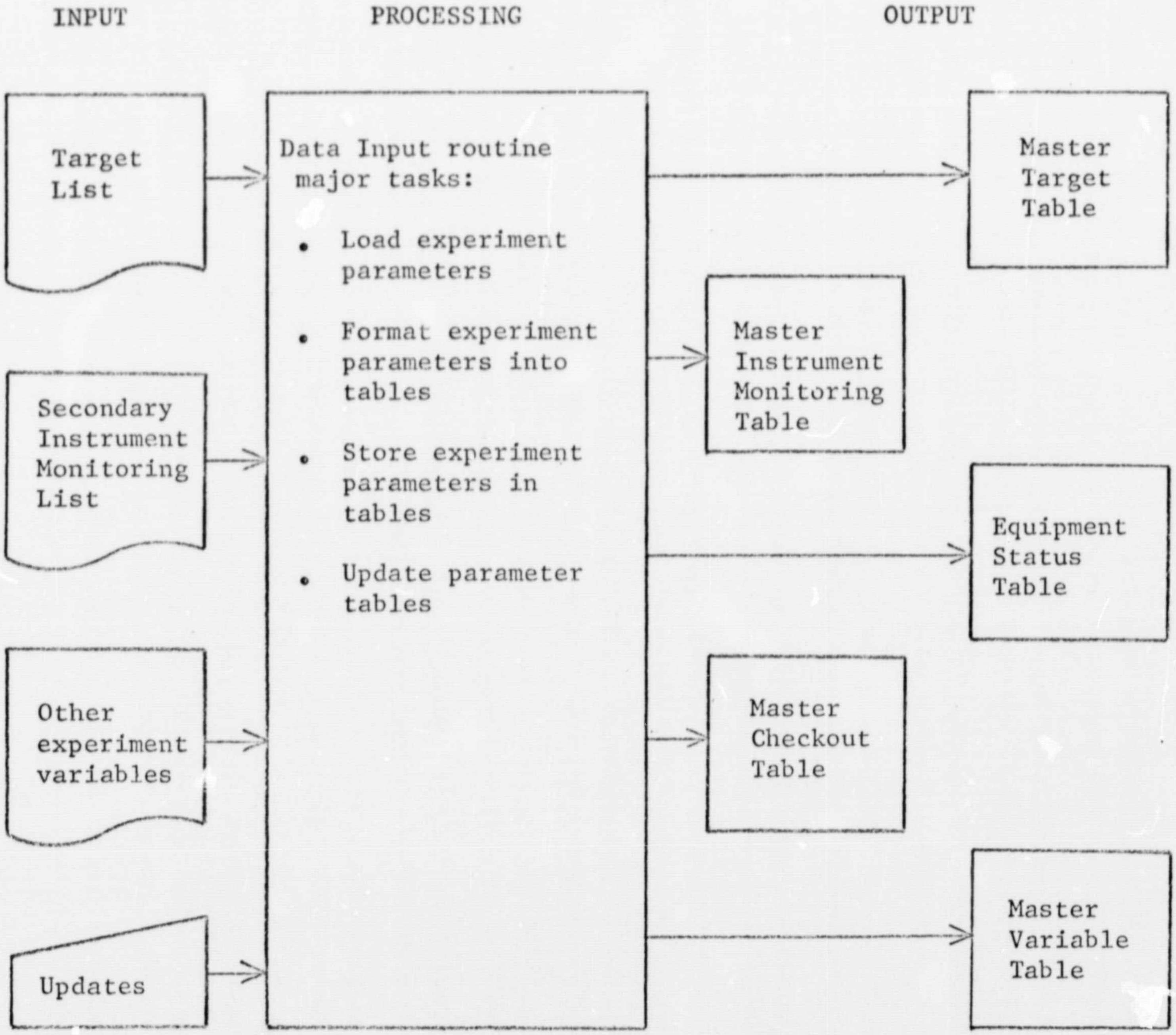


Figure 3-9. Data Input Routine*

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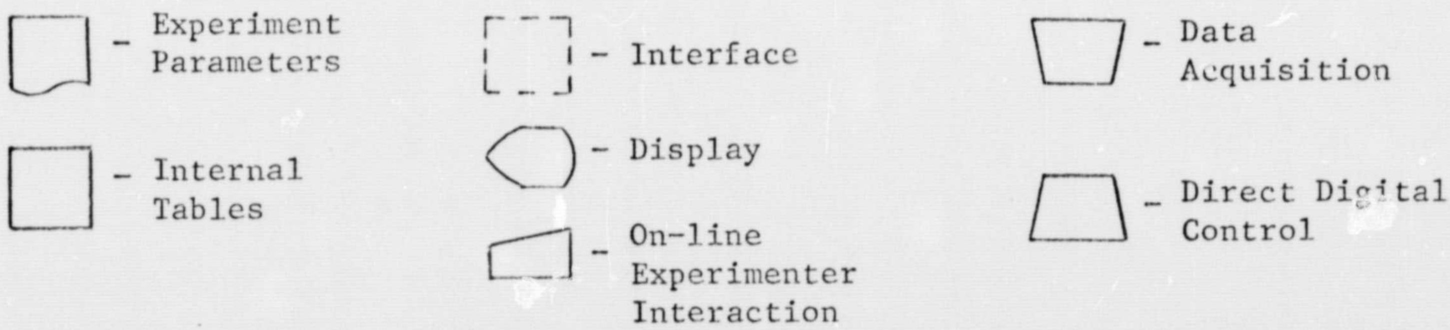
*The following symbol conventions are applicable to Figures 3-9 through 3-20:



3.4.3 Calibration

The Calibration routine is required to perform the calibration of the astronomy module telemetry (see Figure 3-10).

The Calibration routine must initiate the calibration function generator, read its output, and store the calibration curve for later adjustment of telemetry measurements. Also, this routine must provide the capability to check the calibration curve against a known standard and notify the on-board experimenter of gross deviations.

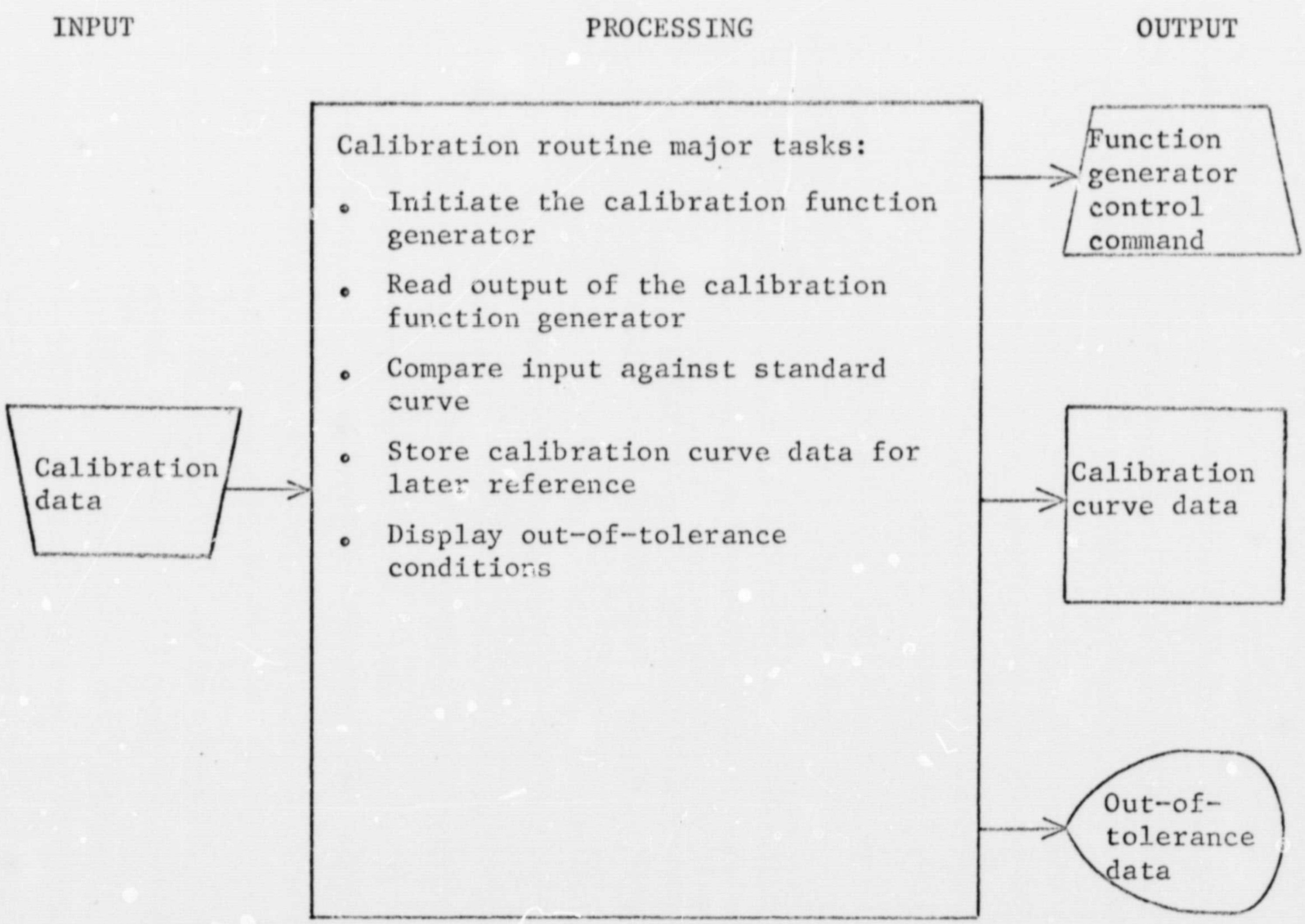


Figure 3-10. Calibration Routine

3.4.4 Experiment Initialization

The Experiment Initialization routine is required to initialize the experiment apparatus (see Figure 3-11).

The Experiment Initialization routine must perform an automatic power-up sequence of the telescope, the polarimeter and all associated instruments, and provide direct digital control of the instrument turret to position the polarimeter at the focal point of the telescope.

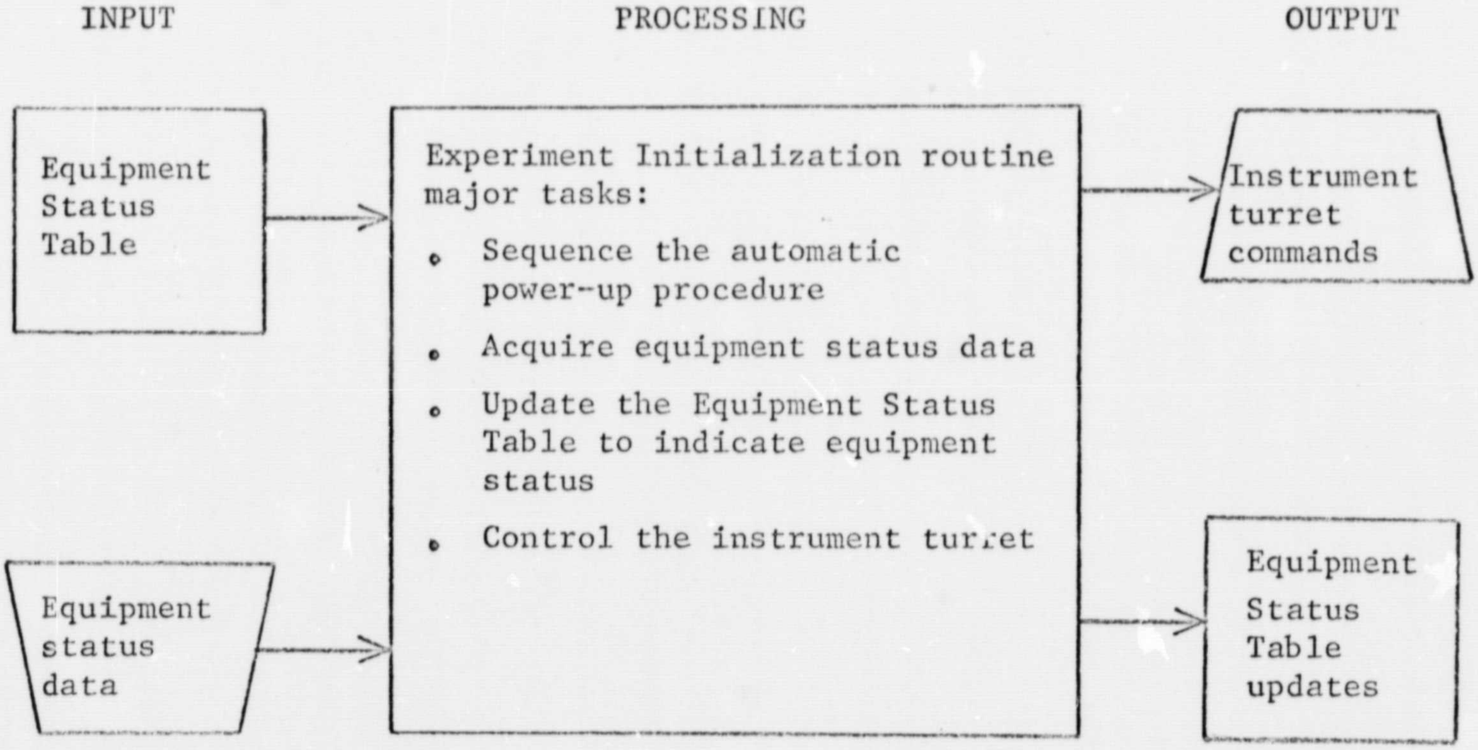


Figure 3-11. Experiment Initialization Routine

3.4.5 Checkout

The Checkout routine is required to determine the operational status of all experiment apparatus (see Figure 3-12).

The Checkout routine must sequence the checkout procedure, provide direct digital control of the checkout instruments, retrieve data, compare the checkout data values against known standards and provide the on-board experimenter with a display of out-of-tolerance measurements. A capability must also be provided in this routine to allow the on-board experimenter to initiate remedial action and to recheck specific measurements on demand.

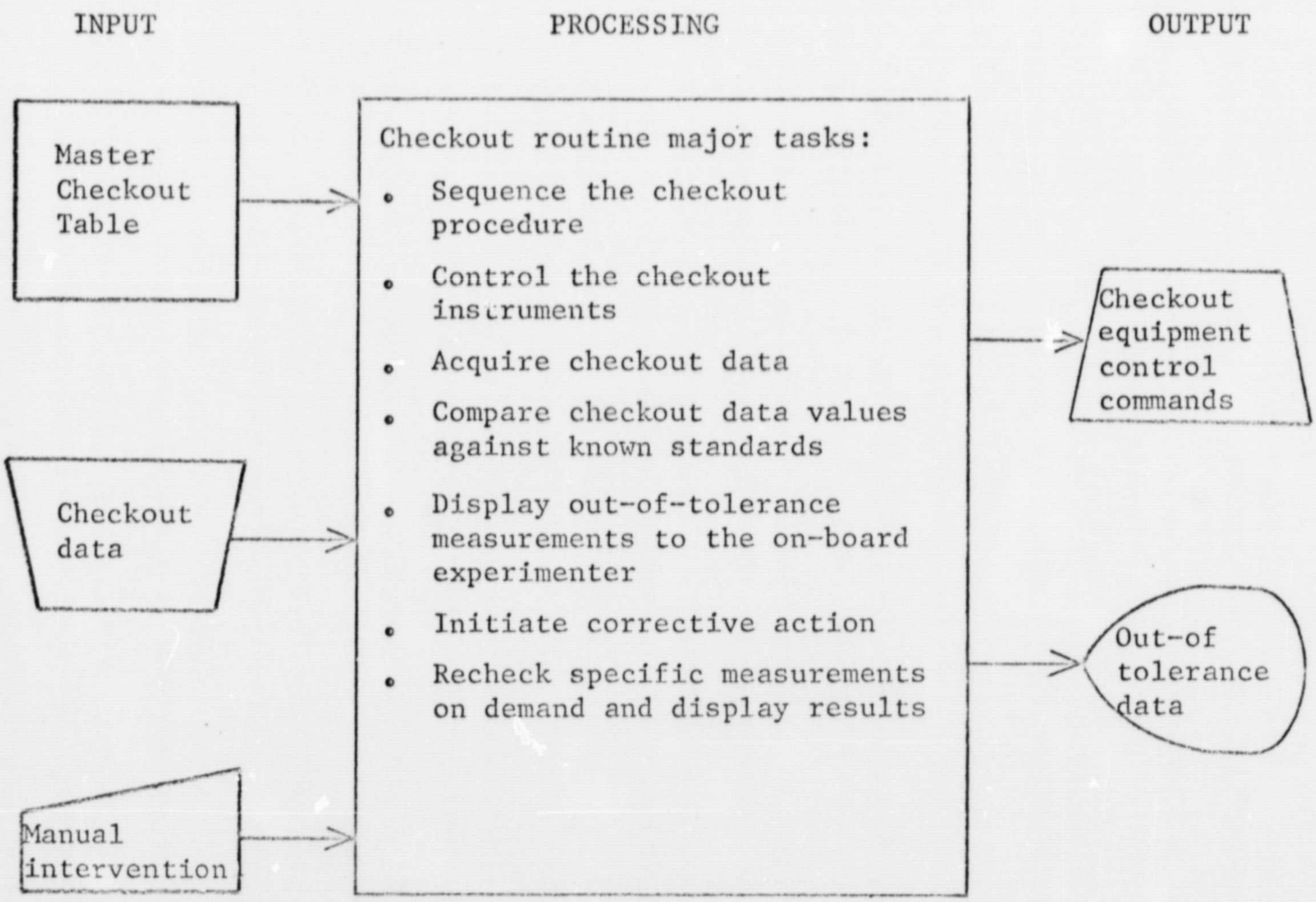


Figure 3-12. Checkout Routine

3.4.6 Target Acquisition

The Target Acquisition routine is required to automatically acquire and track X-ray objects of interest (see Figure 3-13).

The Target Acquisition routine must transform standard celestial pointing coordinates into space reference coordinates for use by the astronomy module pointing and tracking system, and verify target acquisition and accurate tracking to the on-board experimenter through the aspect/display system. In case of misalignment, the on-board experimenter should be able to provide new pointing directions by issuing "fine tuning" commands which the target acquisition routine must convert into required target coordinates to update the target list. If the pre-specified target observation schedule cannot be followed due to anomalies or manual intervention, a revised target sequence must be calculated.

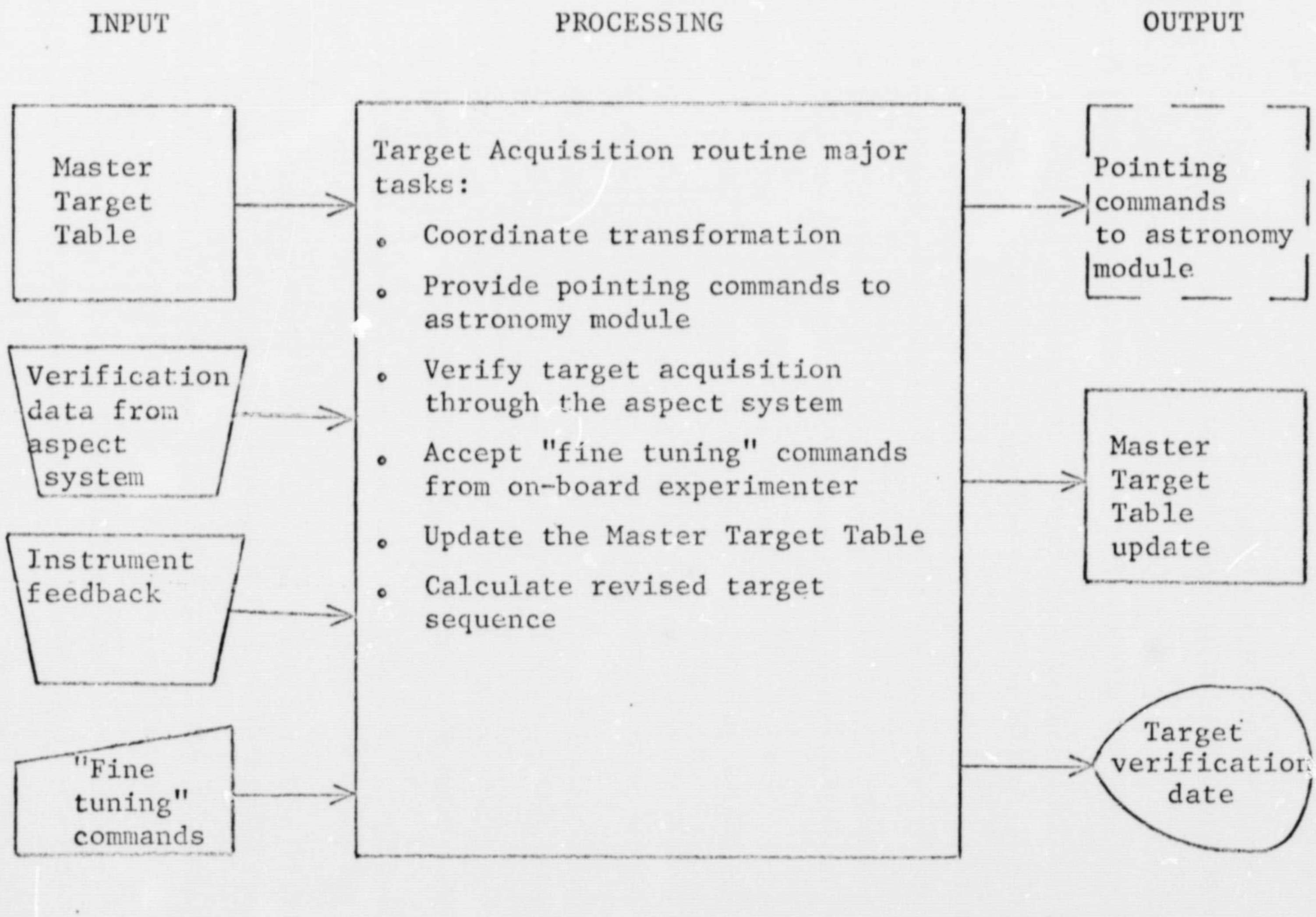


Figure 3-13. Target Acquisition Routine

3.4.7 Primary Instrument Control

The Primary Instrument Control routine is required to provide direct digital control of all primary instruments (see Figure 3-14).

The Primary Instrument Control routine must control the polarimeter table rotation by initializing and stepping the table in accordance with a selected mode of operation; reset all scalers, registers and buffers associated with the beam, anti-coincidence and data counters; and open and close the telescope aperture disc.

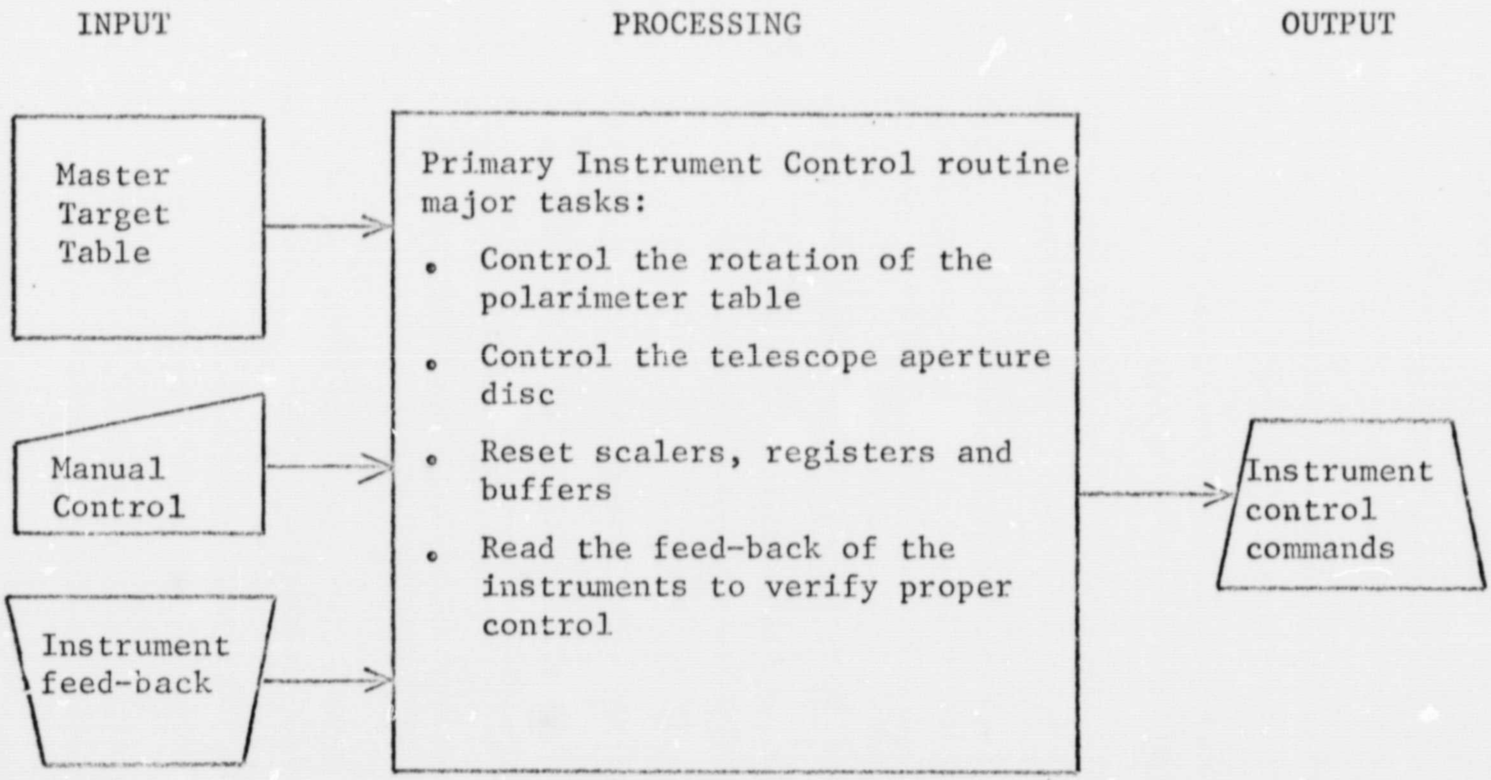


Figure 3-14. Primary Instrument Control Routine

3.4.8 Primary Data Acquisition

The Primary Data Acquisition routine is required to acquire polarimeter data (see Figure 3-15).

Primary Data Acquisition routine must monitor the scaler overflow sensor to detect very high data rates, read the output of the beam, anti-coincidence and data scalers on a periodic basis, and collect the binary string data generated by the pulsar mode detector. All data must be identified and temporarily stored for later analysis.

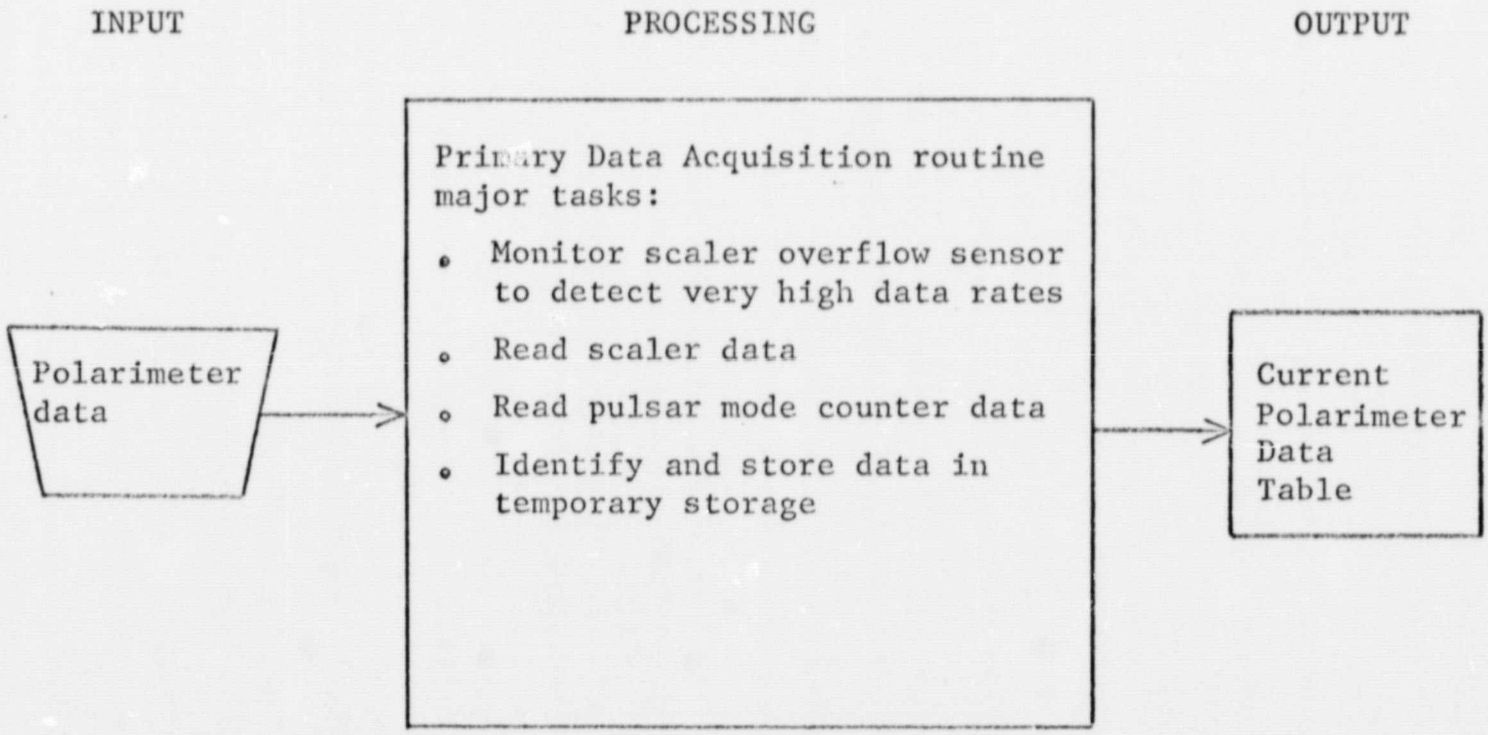


Figure 3-15. Primary Data Acquisition Routine

3.4.9 Primary Data Analysis

The Primary Data Analysis routine is required to analyze the polarimeter data (see Figure 3-16).

The Primary Data Analysis routine must maintain a cumulative total of all scaler outputs for each target along with a cumulative total of exposure time. It must be able to analyze the binary string data from the pulsar mode counter to detect rhythmic variations of radiation intensity. This routine must also provide information for pre-specified, on-demand displays such as the degree of polarization at various energy levels for a specific target.

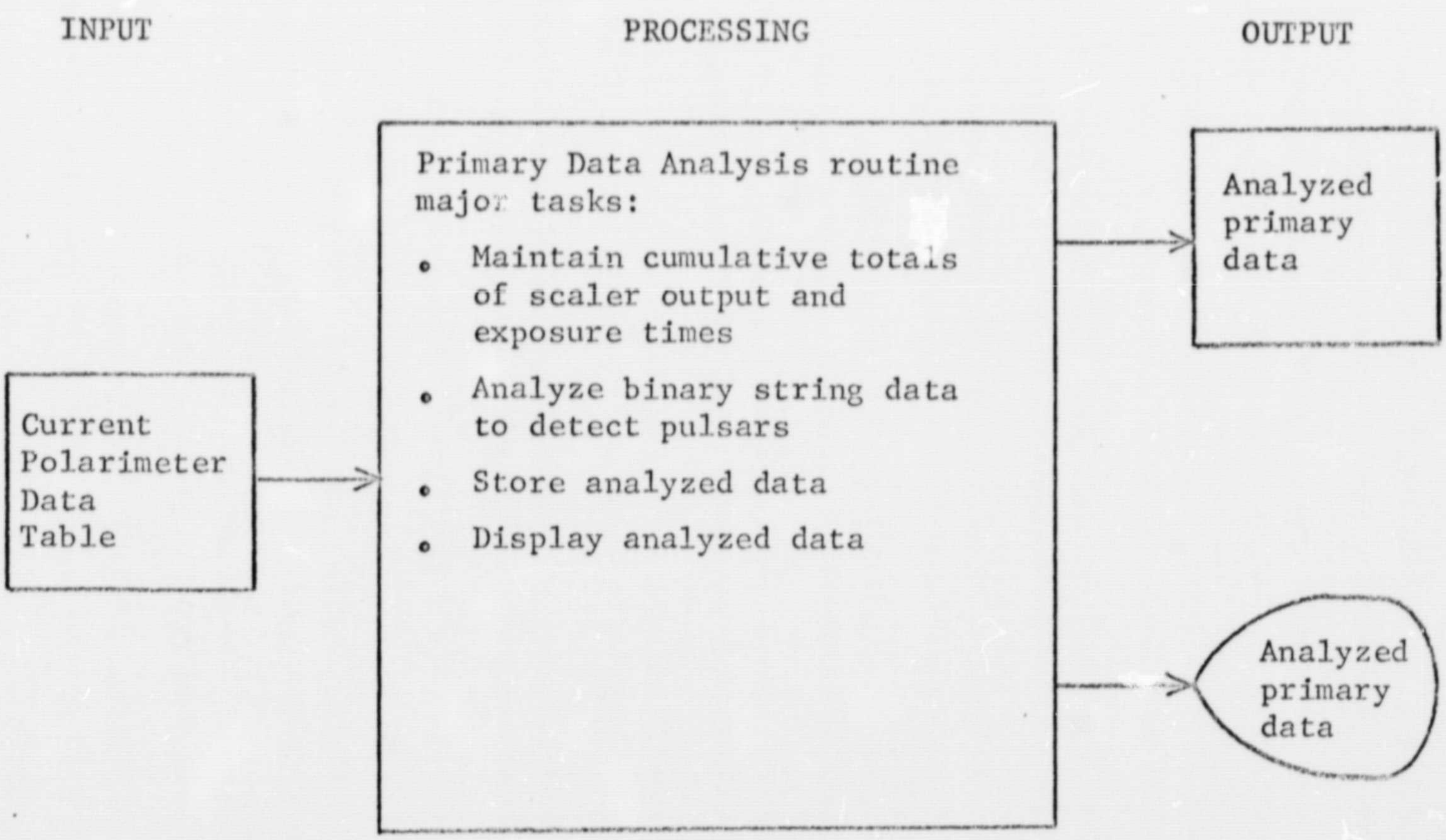


Figure 3-16. Primary Data Analysis Routine

3.4.10 Secondary Data Acquisition

The Secondary Data Acquisition routine is required to monitor all support instruments associated with the polarimeter, the grazing incidence X-ray telescope and the astronomy module (see Figure 3-17).

The Secondary Data Acquisition routine is executed on a periodic basis to detect out-of-tolerance values. Those values which are within pre-specified tolerances are eliminated and an alarm is generated to indicate out-of-tolerance conditions. Emergency routines to correct specific out-of-tolerance conditions may be initiated automatically or at the request of the on-board experimenter.

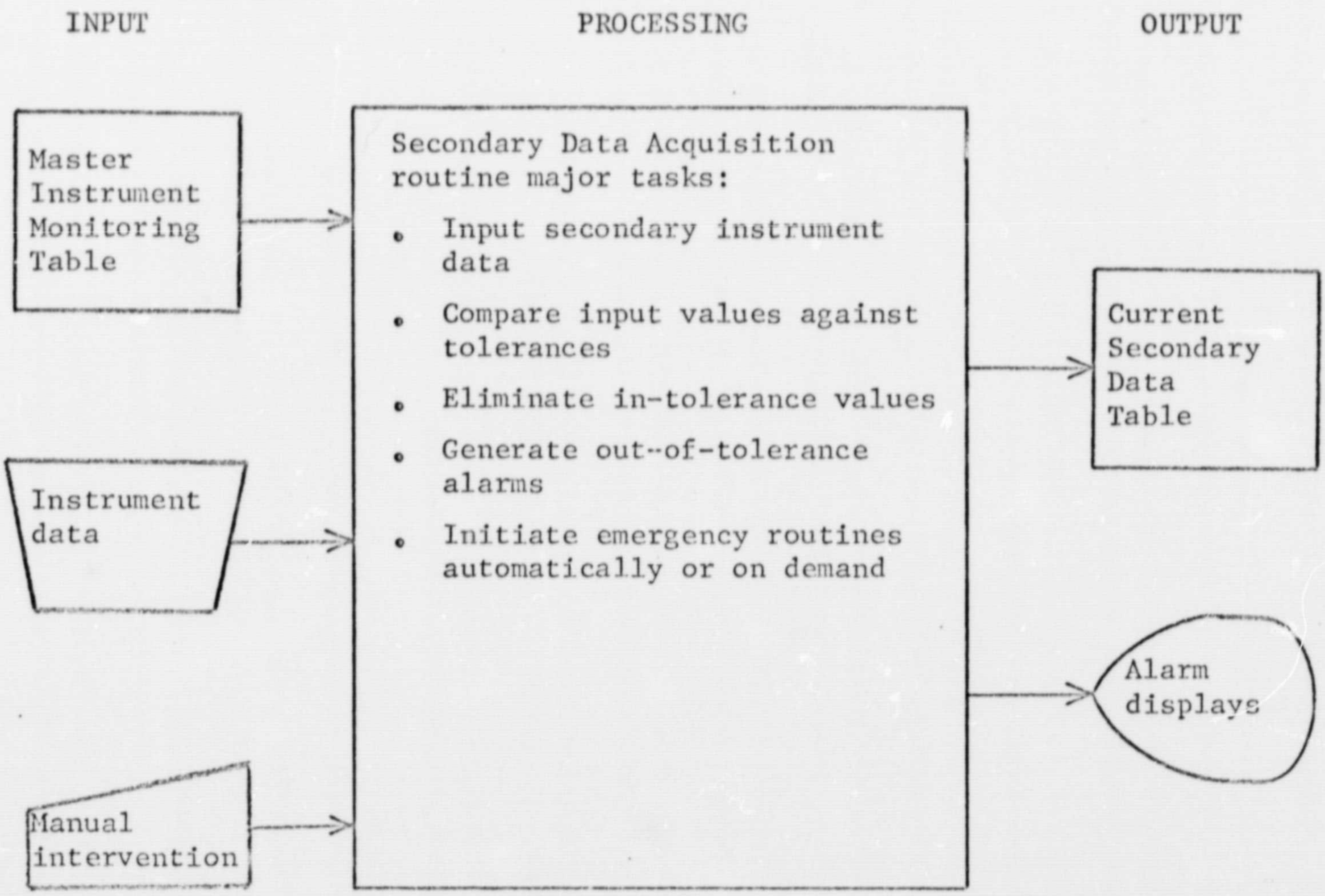


Figure 3-17. Secondary Data Acquisition Routine

3.4.11 Secondary Data Reduction

The Secondary Data Reduction routine is required to significantly reduce the volume of data generated by the secondary instruments (see Figure 3-18).

The Secondary Data Reduction routine must eliminate data values which are redundant, compress the remaining data by various data compression techniques and format the resulting data for storage.

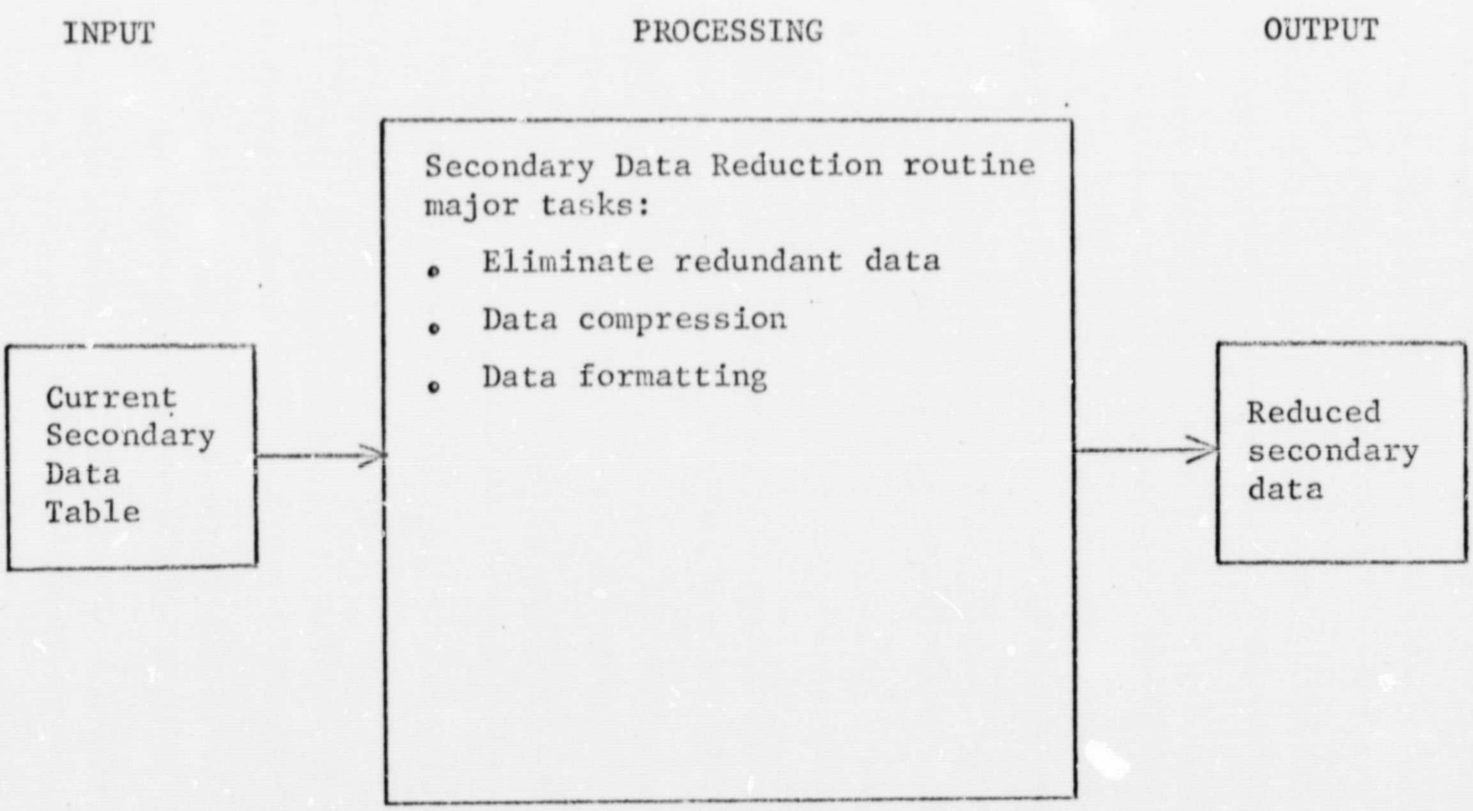


Figure 3-18. Secondary Data Reduction Routine

3.4.12 Data Storage and Transmission

The Data Storage and Transmission routine is required to store and transmit experiment data (see Figure 3-19).

The Data Storage and Transmission routine must store all polarimeter data on retrievable mass storage devices for the duration of the experiment, format polarimeter data for transmission to the ground on demand, and store reduced support instrument data on portable, write-only storage media for delivery to ground via the Space Shuttle.

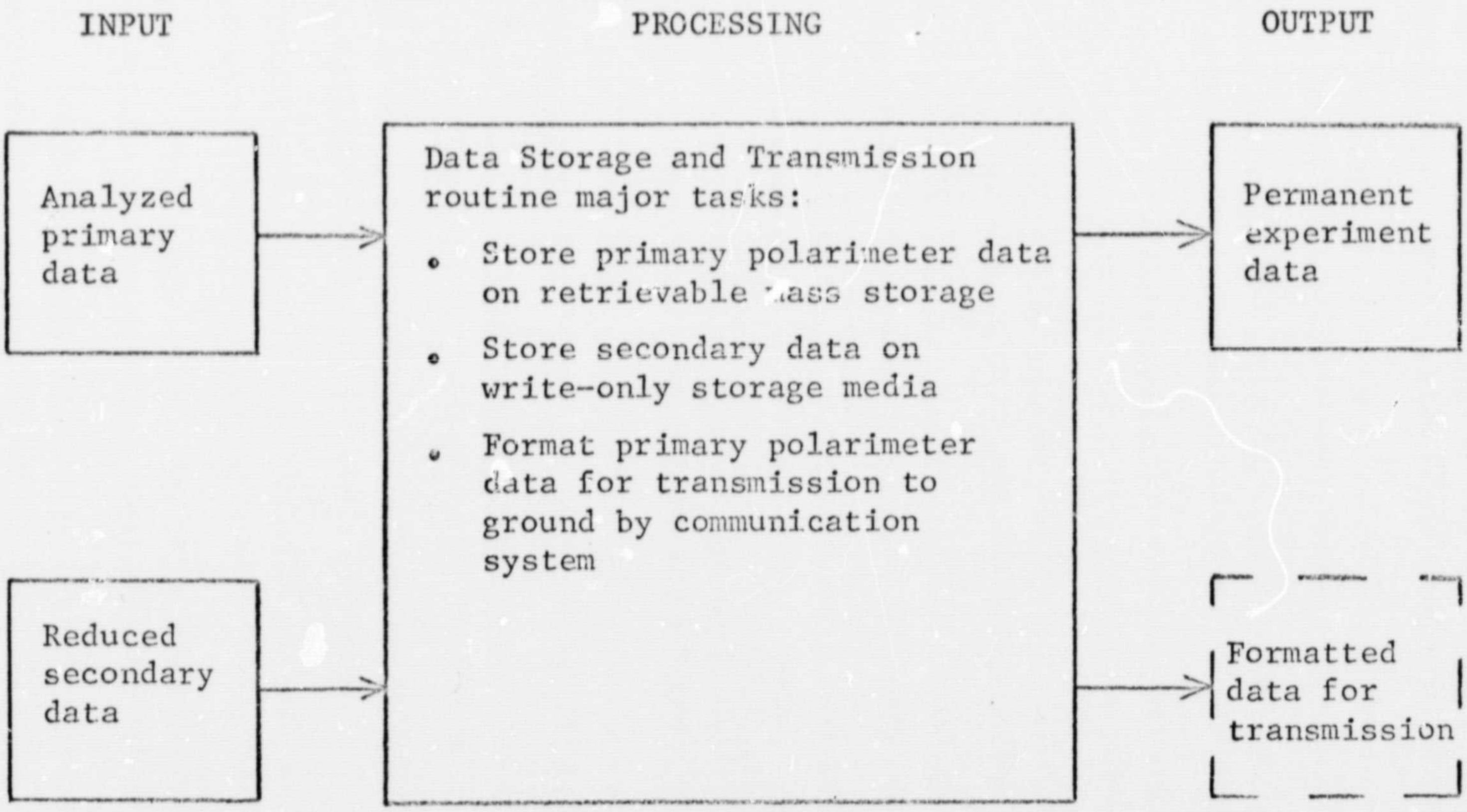


Figure 3-19. Data Storage and Transmission Routine

3.4.13 Automatic Power-Down

The Automatic Power-Down routine is required to remove power from the telescope, polarimeter and associated equipment (see Figure 3-20).

The Automatic Power-Down routine must sequence the power-down procedure, issue direct digital control commands to remove power from specific instruments and verify completion of power-down operations.

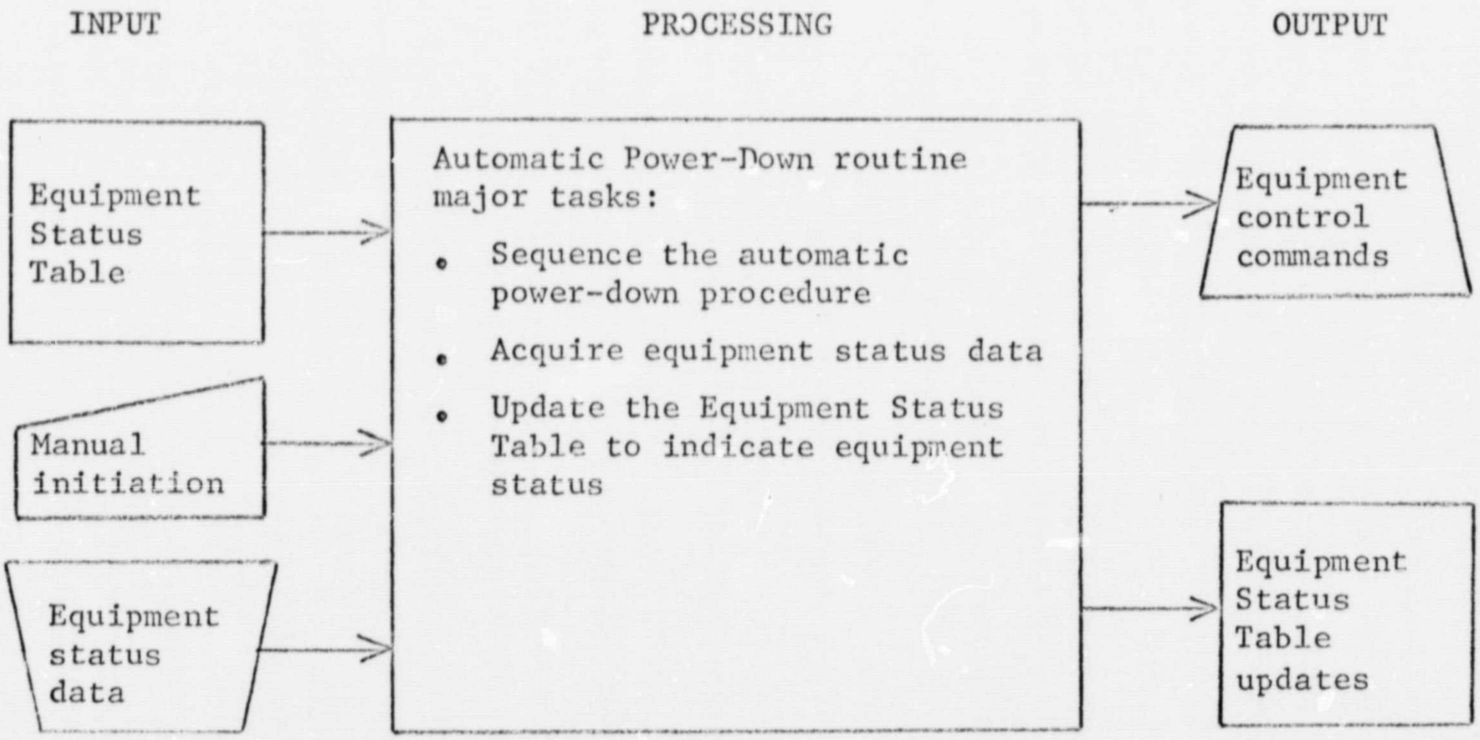


Figure 3-20. Automatic Power-Down Routine

3.5 Hardware Requirements

In order to provide data processing support for those operations indicated in the previous section, special hardware requirements must be considered. Since the X-ray experiment is configured for remote operation aboard a free flying astronomy module, hardware impact on this experiment design as a result of automation is minimal. However, two hardware items have been identified and are described in the following paragraphs as hardware required for automation.

3.5.1 Instrument Control and Measurement Buffer

A special electronic interface device should be provided in the astronomy module with the following capabilities:

- Receive and store instrument control command words
- Decode instrument controls in accordance with command word codes
- Sequence instrument controls in accordance with command word codes
- Receive discrete or digital data for assembly into telemetry format and/or for use in hardware logic inputs
- Provide fail safe logic for critical experiment instruments
- Provide accurate timing and sequencing signals to the instrument sequencer.

3.5.2 Calibration Function Generator

A means is required to perform an end-to-end check of experiment instruments. This requires the inclusion of a special function generator possessing the following characteristics:

- It must be capable of generating a waveform simulation of the output of the proportional counters used by the experiment.
- It must be capable of varying count frequency, amplitude, and rise time characteristics within the range that may exist in actual data.

- It must be capable of inserting the generated signal in place one or more of the counter outputs.
- It must be capable of causing activation of all buffers, analyzers, and logic elements of the polarimeter instrumentation with the exception of the proportional counters themselves.
- It must perform all of the above under control of the experiment· subsystem computer.

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SECTION 4. THE ROLE OF GRAVITY IN CARDIOVASCULAR FUNCTION EXPERIMENT (FPE 5.9)

The circulatory system of mammals, including man, is very specifically adapted to the normal terrestrial gravitational environment. Under normal circumstances significant excursions from this constant acceleration environment are rare and of very short term duration. Extensive experimentation has been carried out in various laboratories concerning the effects of prolonged hypergravity environments on various physiological functions, and it has been found that adaptive functional changes occur in the circulatory system which tend to compensate for the abnormal stresses.

Long term experimentation in a hypogravity environment can be carried out only in a space vehicle in which the weightless state can be achieved. Such experiments have been carried out in conjunction with several space programs conducted by the U.S.S.R. and U.S.A.; however, the resulting data have not proved adequate to define the clinical events associated with long term exposure to hypogravity. Some of these data suggest that an effective nil gravity environment may result in responses qualitatively different than other hypogravity situations. In any case extensive, detailed clinical data are required in order to assess the hazards and to devise protective procedures.

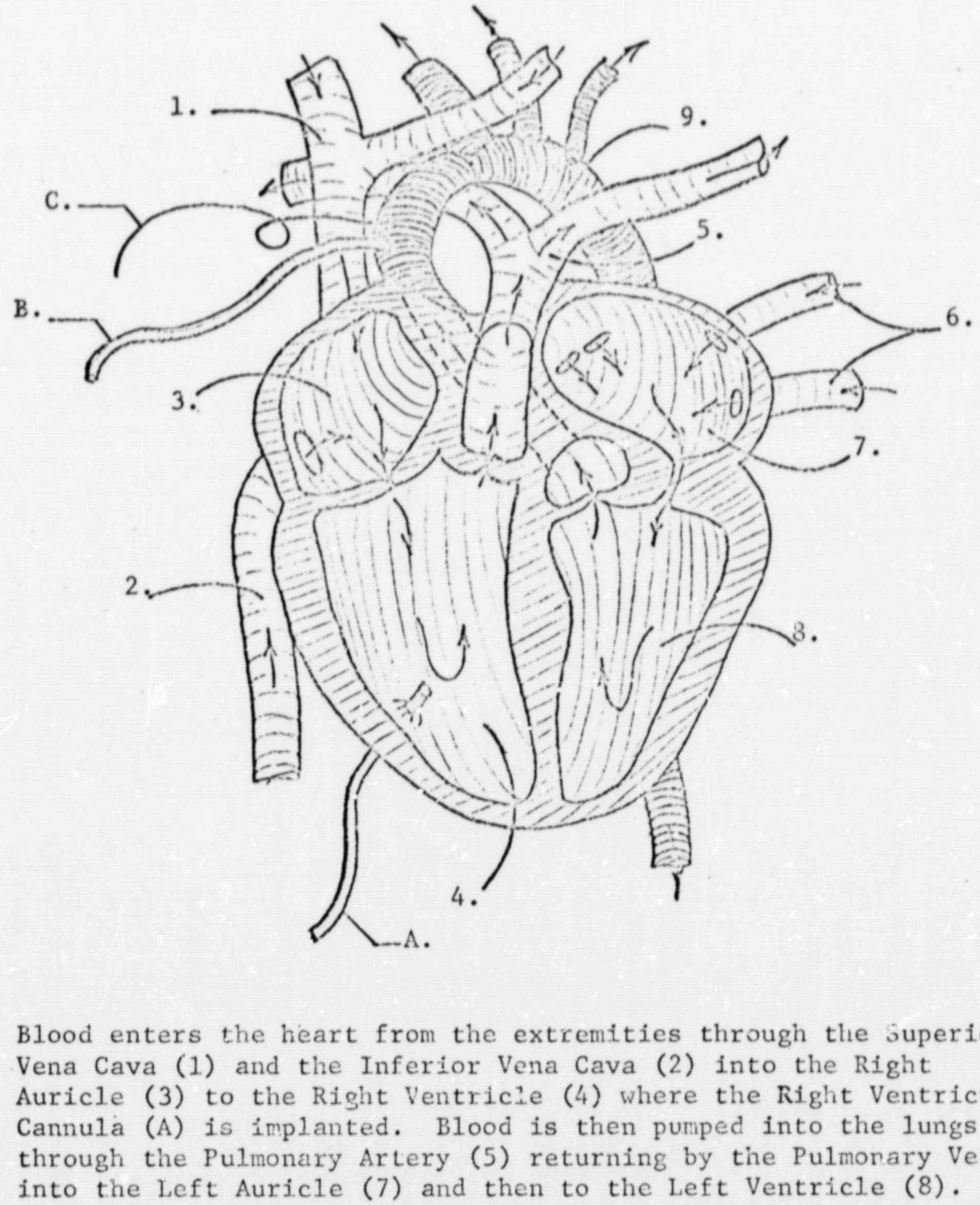
The available data indicate that adaptive responses to nil gravity do, in fact, take place. However, these data are inadequate to define specific experiments. For this reason the proposed experiment involves a generalized monitoring of the circulatory function. The approach is empirical. It is assumed that adaptive or degenerative changes will be detected either during the in-flight experimentation or as the result of post-flight analysis of the experimental data. The most critical aspect of the experiment is that of associating these changes with the gravitational environment. Launch forces, vibration, noise, and other environmental stresses must be avoided where possible, and monitored where they are unavoidable. Environmental monitoring is, therefore, as critical as physiological monitoring, and experiment protocol must be rigidly maintained.[1]

4.1 Experiment Description

Because of their size and handling characteristics, adult white rats have been chosen as best suited for the purposes of this experiment. A technique has been developed which permits the use of unanesthetized and relatively unrestrained animals in studying the effects of long term hypogravity environment. The right ventricle and aorta of the animals are permanently cannulated with small polyethylene cannulas. The cannulas (approximately 0.5 mm diameter) are implanted and exteriorized at the top of the rat's neck. The cannulation does not change in any respect the physiological or psychophysiological state of the animals. Such cannulated animals have withstood tests of exposure to increased G forces of a simulated flight as well as uncannulated control animals.[2] Figure 4-1 presents a simplified heart showing major blood flow and the placement of cannulas.[3]

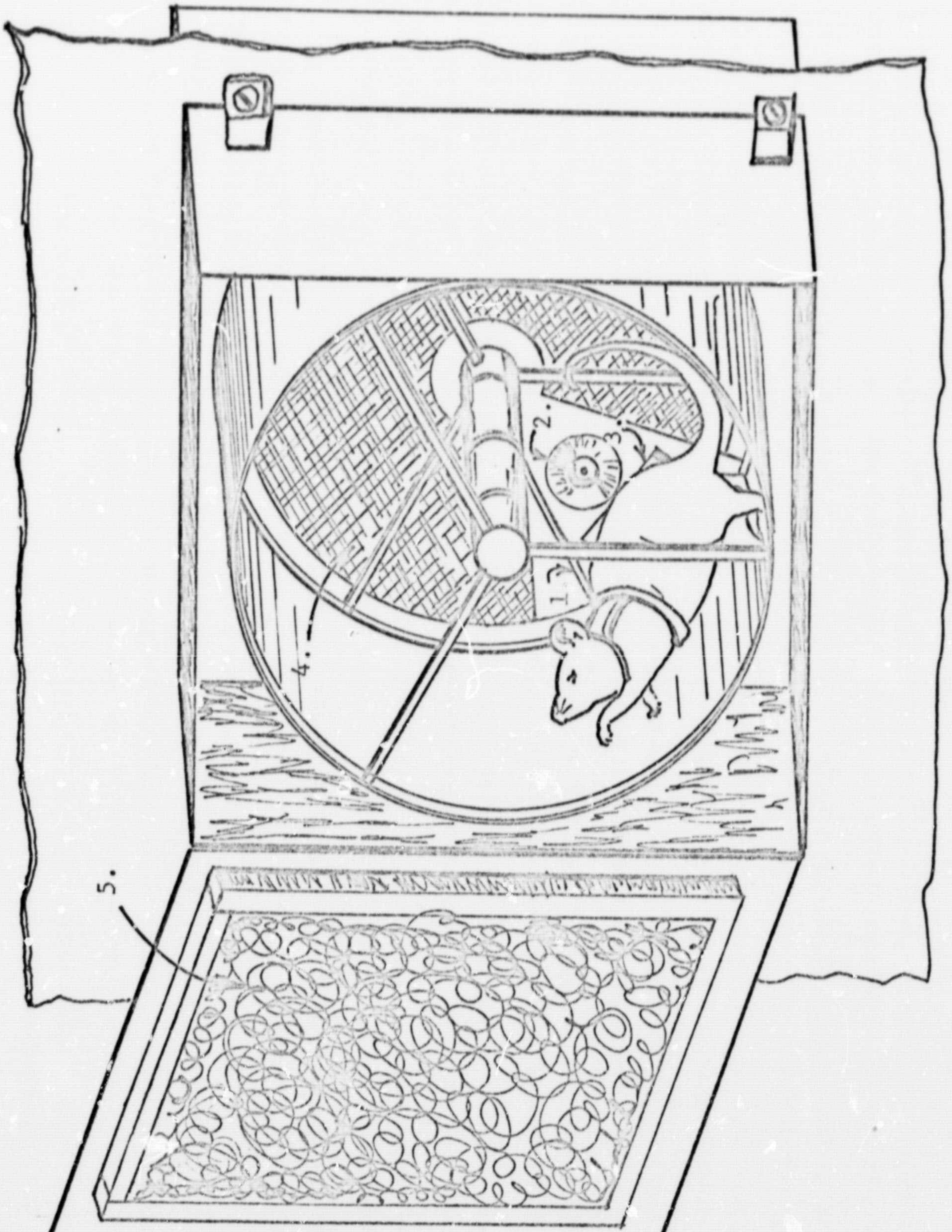
After the implantation surgery the rats are left to recover. They regain their preoperative weight 3-10 days later and continue thereafter to function as uncannulated animals with a survival rate of close to 100 percent.[4] Once recovered, the rats will undergo a period of adaptation. Initially the rats will be maintained in an unanesthetized, unrestrained state while a series of cardiovascular studies are performed. These studies include all of the measurements which are expected to be made in space and are necessary to obtain the experimental data for a ground baseline. Approximately four weeks will be required to establish this baseline.[5]

Each cannulated rat is then fitted with a harness restraint mechanism and placed in the experiment cage. This cage provides for the semi-restraint of the rat by a restraining arm which attaches to the harness.[6] Provision is made to move about by having the cage rotate about a center hub in tread-mill fashion. Figure 4-2 illustrates how a rat will be housed in such a cage. The cage center hub is fixed with respect to the external housing. This provides a path through which implant lines are routed.



Blood enters the heart from the extremities through the Superior Vena Cava (1) and the Inferior Vena Cava (2) into the Right Auricle (3) to the Right Ventricle (4) where the Right Ventricular Cannula (A) is implanted. Blood is then pumped into the lungs through the Pulmonary Artery (5) returning by the Pulmonary Vein (6) into the Left Auricle (7) and then to the Left Ventricle (8). It is then pumped through the Aorta (9) to the extremities. The Aortic Cannula (B) and Temperature Sensor (C) are implanted in the Aorta in close proximity to the heart.

Figure 4-1. Simplified Heart Showing Blood Flow and Cannulation



1. Restraining Arm, 2. Rat Actuated Water Supply, 3. Food Pellet Dispenser, 4. Air Inlet Screen, 5. Debris Trap and Filter Mounted in Cage Door (Door is shown in open position)

Figure 4-2. Experiment Rat Cage

Following a two-week period in which they become accustomed to their cage and harness, 15 of the 30 cannulated rats will be transported to the Space Station. The remaining 15 rats will serve as a ground control in a carefully maintained one-G environment.* An identical experiment plan will be carried out for both space oriented rats and their ground controls. Each rat will be housed in its own cage which will be supplied with a carefully controlled environment. Food will be provided automatically in pellet form and rat actuated containers will supply water. Air flow through each cage will be sufficient to carry food debris, feces, and urine into a debris trap and filter at one end of the cage. Lighting will be controlled to maintain a preset day/night cycle.[7]

4.1.1 Primary Instruments

The primary instruments which are vital to the successful conduct of the experiment are**:

- Blood pressure measurement instruments
- Electrocardiograph (EKG)
- Cardiac output measuring equipment
- Blood gas analyzer
- Deep body temperature sensor
- Atmospheric gas analyzer

Figure 4-3 is a simplified diagram of the apparatus used to obtain all primary measurements for one rat with the exception of atmospheric gas analysis. For the sake of simplicity, most electrical components have been omitted. However, it should be clear to the reader that through proper signal conditioning and buffering, all requisite control and monitoring functions can be satisfactorily accomplished.

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*If an on-board centrifuge were available which could provide all of the environmental conditions of the Space Station except zero-G and would not introduce any new anomalies, part of the control group could be placed on the centrifuge. However, because of the extreme difficulty of mounting the specimens, racks, instruments, control apparatus and automatic housekeeping devices on the centrifuge to provide a valid control, it is felt that the on-board centrifuge could be omitted in favor of ground based controls./8/

**If an Electromyograph (EMG) is required, data will be obtained from electrodes implanted in a back muscle of each rat. However, since cardiovascular functions are of primary interest in this experiment, EMG data is not of great value./9/

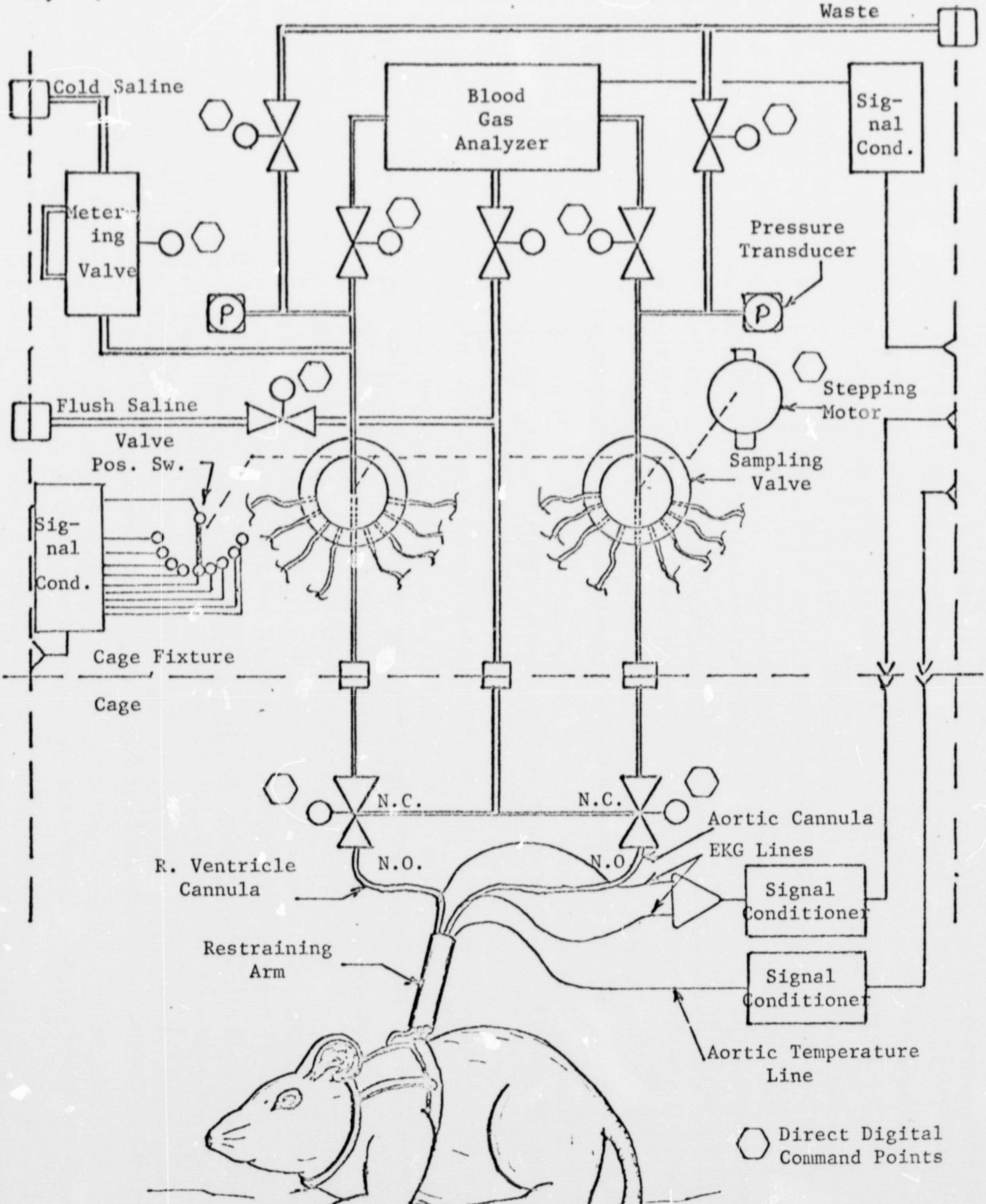

Figure 4-3. Primary Apparatus Assembly

Each of the two cannulas are normally filled with a sterile saline solution. This provides several benefits:

- It keeps the tubing clean
- It provides a direct hydrostatic pressure line into the heart interior
- Because saline is electrically conductive, it provides good electrical paths to two points within the heart.

Several features of Figure 4-3 should be noted. The blood pressure, blood gas analysis, and cardiac output measuring instruments are common to all rats. This is made possible by a stepping motor operated, dual chamber sampling valve. In order to cleanse this valve and the other common lines, a saline flush system is included. This flush system provides for the purging of all lines and instruments between the rat cage and the rest of the system. Because the line lengths required for blood sampling must be kept to a minimum, the rat cages should be located in close proximity to each other and to the experiment apparatus. To reduce noise pickup on electrical lines, the rat cages should be provided with electrostatic shielding and initial signal conditioning accomplished within that shield.

4.1.1.1 Blood Pressure Measurement Instruments. By closing off all lines to the cannula with the exception of lines to sensitive pressure transducers, blood pressure in the right ventricle and aorta may be read. These readings provide peak contraction and relaxation pressure and heart rate data.

4.1.1.2 Electrocardiograph (EKG). Electrodes placed in each of the polyethelene cannula in close proximity to the rat will register the electrocardiographic difference of potential between the two cannulas.[10]

4.1.1.3 Cardiac Output Measuring Equipment. Cardiac output monitoring employs a variation of the now standard dye-dilution technique which is widely employed. A meter valve, capable of injecting a metered slug of cold saline into the right ventricle is used in conjunction with a temperature sensor implanted in the rat's aorta to measure blood flow as a function of time.[11]

4.1.1.4 Blood Gas Analyzer. The oxygen content of the blood is monitored by a special design blood-gas analyzer. Such analyzers use the principle of polarography to determine the concentration of dissolved gases in the blood. Commercially available units now give accuracies of ±2 percent in a 10 second reading.[12]

4.1.1.5 Deep Body Temperature Sensor. Deep body temperature is measured using the same temperature sensor as is used for cardiac output measurement. The sensor is a standard biomedical transducer implanted in the aorta at the time of cannulation, exteriorized at the same location as the cannula, signal conditioned, and monitored by the data processing system.[13]

4.1.1.6 Atmospheric Gas Analyzer. Figure 4-4 illustrates how a mass spectrometer in conjunction with the necessary sampling lines and valves might be used to obtain an accurate analysis of the gaseous composition on the rat's breathing mixture as it enters and exits from each cage. Since the EC/LS System for all specimens is common, only one inlet line is necessary for inlet gas monitoring. The sampling valve shown switches the sampling inlet from one cage to the next to obtain samples under remote control. The mass spectrometer is patterned after one developed by NASA for the analysis of breath samples of pilots and astronauts. This spectrometer is capable of analyzing a sample of gas mixture for twelve composite gases to an accuracy of ±2.5 percent within 1/10 of a second.[14] By correlating O_2 and CO_2 inlet and outlet partial pressures it will be possible to determine the oxygen consumption of each specimen rat.

4.1.2 Secondary Instruments

The following secondary instruments are required to support this experiment:[15]

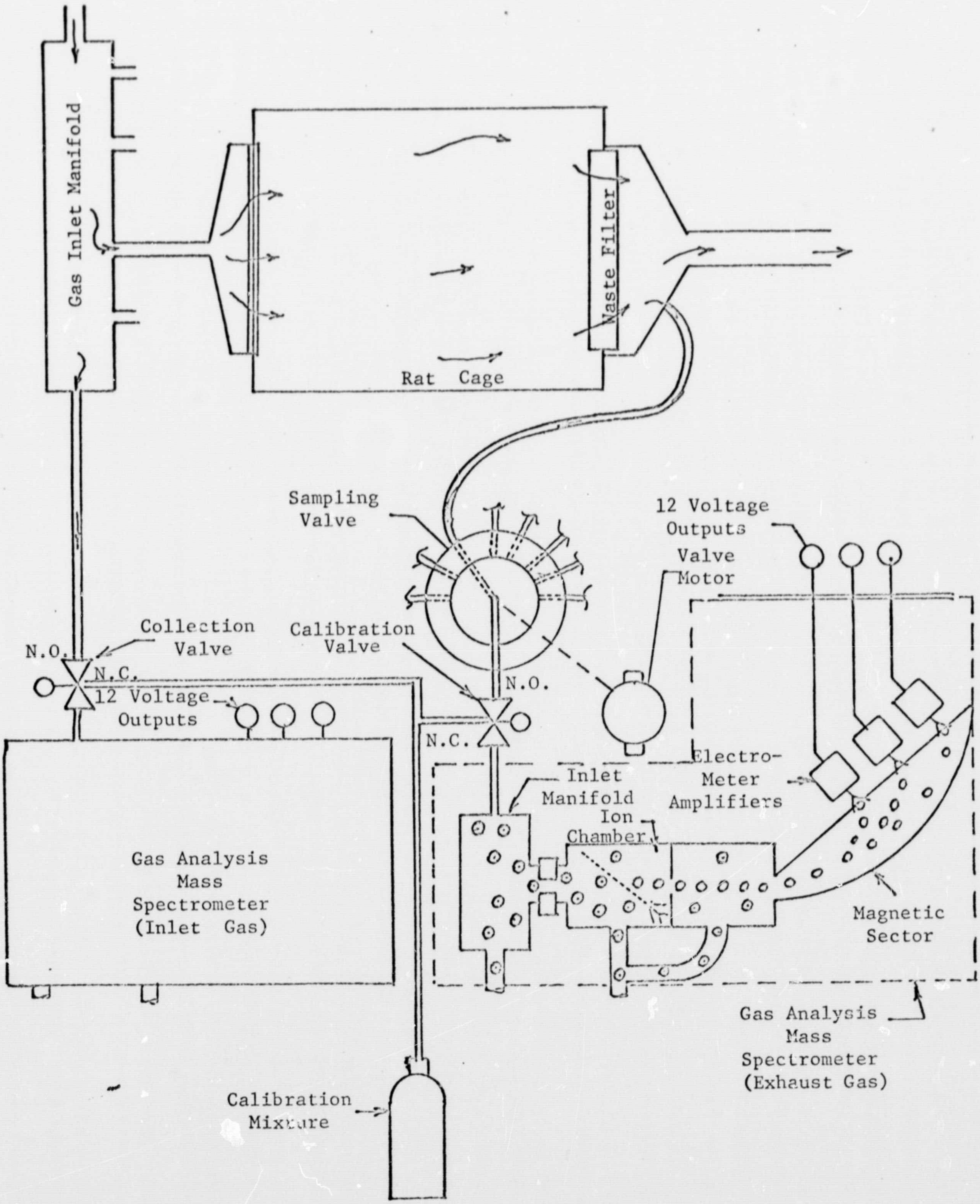

Figure 4-4. Atmospheric Gas Analyzer

Instrument	Measurement Taken
Accelerometer	Acceleration and Vibration
Microphone and Audio Analyzer	Noise
Geiger and Scintillation Counters	Radiation
Thermistors	Ambient Temperature
Hygrometer	Relative Humidity
Photometer	Illumination Intensity
Force Balance Flowmeter	Atmospheric Gas Flow

If a suitable rack arrangement is provided for the specimen cages, only one set of instruments is required for the first three instruments.

Many other measurements will be made within this experiment as a function of the overall Space Station "housekeeping" data system. For the purpose of this study it is sufficient to state that such measurements will be retrievable by the experiment subsystem data processor in the event that additional supporting information is required.

4.2 Experiment Operations

This study of the effect of a zero gravity environment on small mammals is conducted in three phases--pre-flight, in-flight, and post-flight. Although only those operations which occur on board the Space Station are of direct relation to this study, the discussion which follows describes ground as well as space operations. This is necessary to give continuity to the overall experiment procedure.

4.2.1 Pre-Flight Operations

Section 4.1 describes the steps taken to prepare experiment specimens and to establish a pre-flight ground baseline. Following this preparation, the rats will be transported to the Space Station. Each rat will be housed in its individual cage, isolated, restrained, and protected so far as possible from extreme launch forces. Launch accelerations, vibration, noise, and atmospheric parameters will be recorded during the space flight. Provision will be made aboard the transport vehicle to assure adequate temperature, atmospheric conditions and waste disposal facilities. Upon docking with the Space Station, the specimen cages will be transferred to the Bio-D laboratory where they will be placed in the appropriate racks and connected to the necessary gas, liquid, and electrical manifolds.[16]

4.2.2 In-Flight Operations

Experiment protocol requires that with the exception of the handling required for initial installation and possible emergency measures, each rat should be effectively isolated during the total experiment cycle. Such isolation assures the validity of any observed effects of the zero gravity environment on the rats and reduces required manual operations. In-flight operations may generally be classified as follows:

- Periodic measurements
- Continuous measurements
- Manual operations

4.2.2.1 Periodic Measurements. The most important and complex data that must be taken during in-flight operations are those measurements of the primary cardiovascular functions which are made on a regular periodic basis. All of these measurements will be taken from a single rat before the next rat is examined.[17] This procedure will allow the cross correlation of experiment data with time. The measurement sequence should be repeated at least every six hours and more often if possible. Resultant data will be reduced, formatted, displayed, stored for future reference, and made available in compact form to researchers on the ground. A typical primary data taking sequence might be carried out in the following manner:

- Check out all primary instruments.
- Calibrate the blood gas analyzer, atmospheric gas analyzer, and EKG.
- Perform the following operations for each rat:

  Begin the sequence by analyzing the cage atmosphere for gas partial pressure, relative humidity, flow rate, and temperature.

  Select the specimen to be examined by stepping the cannula sampling valve to the proper position.

  Measure the aortic blood pressure as an analog value from the aortic cannula pressure transducer.

  Measure the ventricular blood pressure as an analog value from the ventricular cannula pressure transducer.

  Measure EKG as the differential voltage between the saline columns in the two cannula.

  Perform blood oxygen content analysis by first flushing the cannula with saline and then withdrawing a blood sample into the automatic blood gas analyzer. Output is provided digitally by the analyzer.

  Read deep body temperature as an analog output from the aortic implanted thermistor.

  Determine cardiac output by injecting a small slug of cold saline into the right ventricle and noting the time required to detect a temperature dip in the right aortic thermistor. This time is compared with empirically obtained data to determine blood flow rate.

  Store all primary data for the specimen in retrievable storage along with the time of observation.

4.2.2.2 Continuous Measurements. A number of parameters must be sampled on a continuous basis. Most of these are commonly referred to as housekeeping data, but some involve the simplified sampling of primary instrumentation. Measurements of temperature, humidity, pressure and atmospheric flow rate should be made for each of the specimen cages. Vibration and noise, acceleration, lighting conditions, high energy radiation, and the breathing mixture gas composition should be monitored for all specimens collectively. In addition, a simplified check of specimen EKG will provide a vital life sign monitor. All of these measurements will be checked against pre-established high and low values which, if exceeded, will result in the generation of an alarm within the Space Station.

Each of the above parameters will be recorded on an hourly basis to serve as background information in post-experiment analysis and as supplemental data for the study of physiological anomalies or engineering malfunctions.

4.2.2.3 Manual Operations. Certain operations have been assigned to the on-board experimenter. A periodic visual inspection of each rat will be made to provide a gross anatomical analysis and to determine the overall condition of the experiment instrumentation. The on-board experimenter must also look after the replenishment of experiment consumables, clean and maintain the specimen cages, and observe excessive or deficient consumption of food and water and any unusual deviation in the volumes and rates of defecation and urination. In addition, he must be available to carry out emergency procedures in the event of experiment anomalies and to confer with ground investigators in the conduct of ad hoc research activities.[18]

4.2.3 Post-Flight Operations

Following an eight week period in space, the rats in their cages will be returned to the earth. During this final phase of the experiment, the same physiological measurements will be made.[19] These post-flight operations may last for several months since it is possible to maintain the rats in their cannulated state for extended periods of time.

4.3 Selection of Operations for Computer Support

Two factors place heavy demands on the on-board data processor for computer support of this experiment. First, there are scores of measurements of low to medium rate which must be monitored. In most cases this involves a simple record keeping operation, but in some cases rather complex analysis must be performed. The ability to set normal operating limits on measurements to detect unexpected events is important. The reduction of telemetry requirements by automatically deleting redundant data also adds to the computer workload. Second, since it is desirable to disturb the specimen rats no more than necessary, automatic controls will be used to the greatest extent feasible for all data taking and housekeeping operations which might otherwise require physical handling of the rats.

Operational functions which have been identified for data processing support are described as follows:

- Such routine tasks as must be performed to maintain all vital experiment apparatus in good working order should be provided data processing support. Since this experiment has no "down" time during which major overhauls might be performed, all maintenance must be performed with the system on line. Preventive measures to reduce equipment failure will be important.
- Emergency routines should be provided to assist the experimenters in overcoming emergency conditions and to provide a maximum data return of all emergency related parameters.
- Because of the number of devices involved, regular checkout of primary and secondary instruments should be automatically performed.
- The capability to automatically sequence the data taking operations in accordance with the overall experiment protocol should be provided.
- All control and monitoring operations required for performing the primary data taking sequence described in Section 4.2.2.1 should be automated. This is necessary in order to shorten the time required for observing each specimen and to improve repeatability.
- All primary data should be automatically collected, sorted, and stored in retrievable memory along with such background and secondary data as may be required for the generation of displays, future reference on the ground or in space, or for inclusion in more complex data processing operations.

- Displays of pre-specified data should be provided automatically. These should include such structured graphics as are needed to show trends or anomalies.
- The ability for on-demand call-up of specific experiment data is required for both ground and space observation. The ability to assign high/low alarm limits to specific measurements should also be provided.

4.4 Software Requirements

This section presents the software requirements for the operations selected for automation in the previous section. The software design for the Role of Gravity in Cardiovascular Function experiment is presented in Figure 4-5. This diagram presents the major routines required to automate this experiment. Requirements for each major routine are presented in Sections 4.4.1 through 4.4.10.

4.4.1 Experiment Executive

An executive routine is required to perform overall control of the experiment sequence. This routine must sequence, initiate and verify all experiment operations including data input, instrument checkout and calibration, primary instrument control, and acquisition, analysis, reduction, display, storage, and transmission of experiment data.

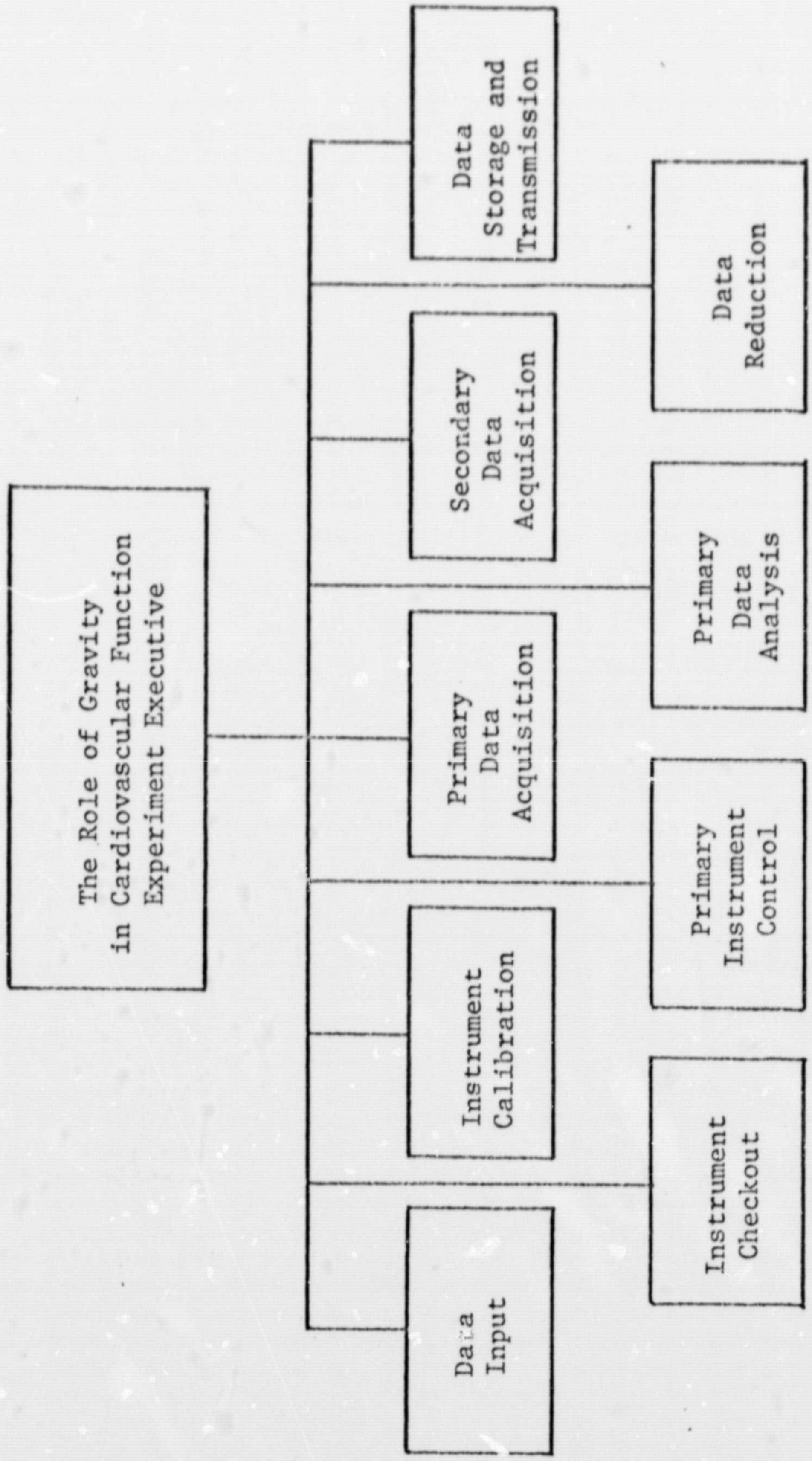

Figure 4-5. Software Design for The Role of Gravity in Cardiovascular Function Experiment

4.4.2 Data Input

A data input routine is required to load and process experiment input variables (see Figure 4-6).

The Data Input routine must accept, and store in table form, the list of secondary measurements to be monitored during the experiment. This list will include the measurement address, sampling frequency, type of measurement, tolerance, etc. This routine must also be able to update the Master Checkout Table by processing additions, modifications or deletions. In addition, this routine must input and store all experiment variables.

The Data Input routine must be capable of accepting on-line updates during experiment operation due to experiment redirection or emergencies which may effect the sequence of experiment operations.

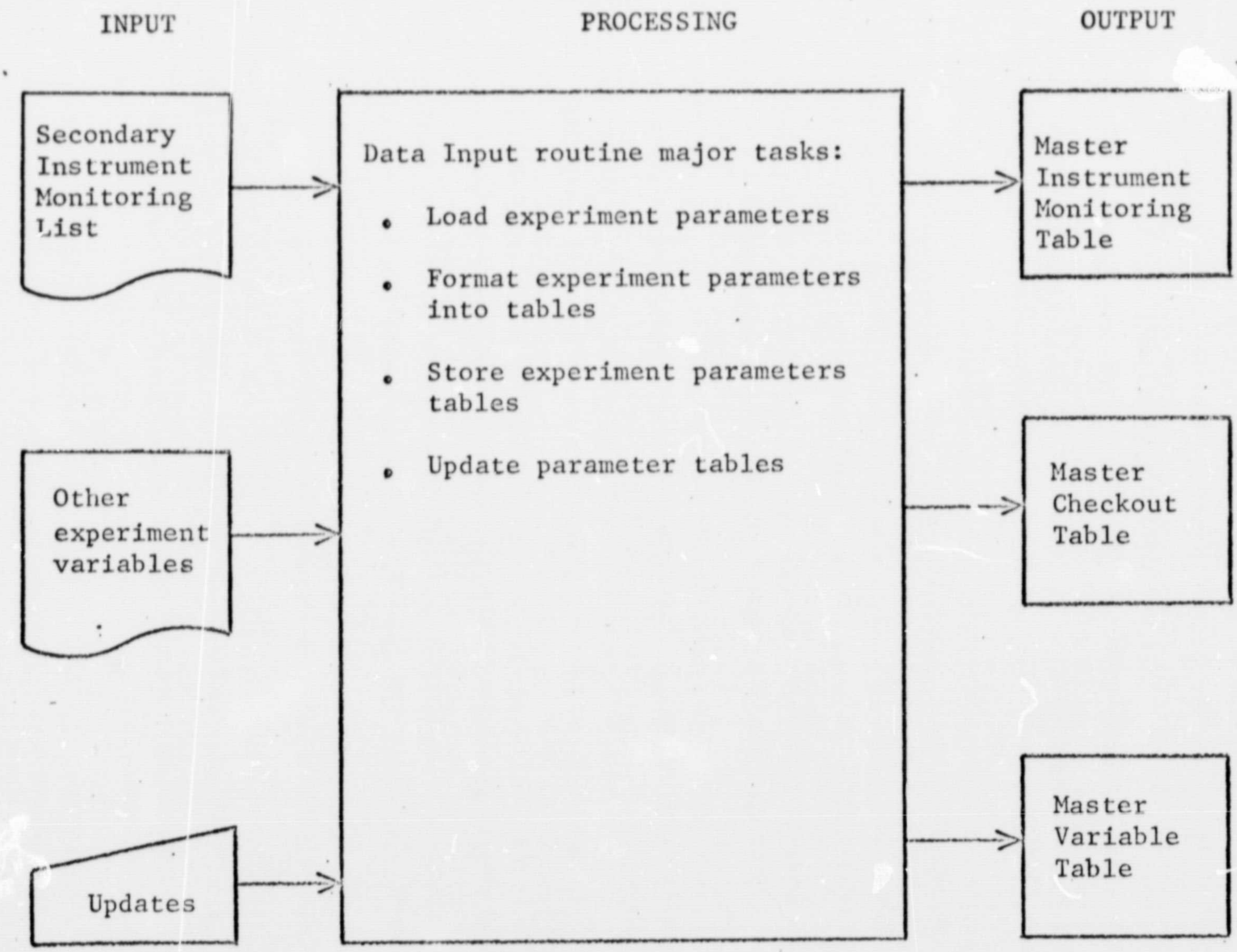

Figure 4-6. Data Input Routine*

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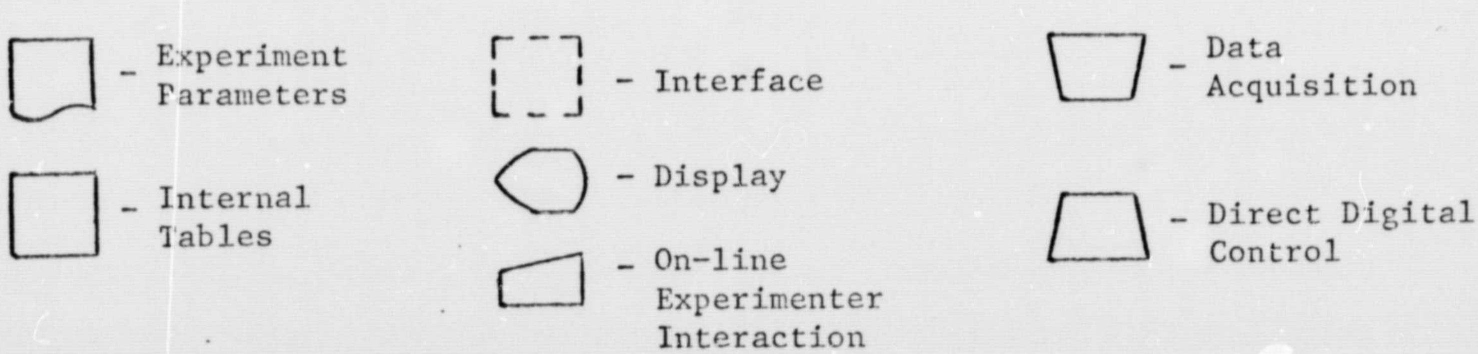
*The following symbol conventions are applicable to Figures 4-6 through 4-14:



4.4.3 Checkout

The Checkout routine is required to establish the operational status of all experiment apparatus (see Figure 4-7).

The Checkout routine must sequence the checkout procedure, issue direct digital control commands to control the checkout instruments, acquire data from the checkout instruments, compare the checkout data values against known standards and provide the on-board experimenter with a display of out-of-tolerance measurements. The on-board experimenter must also be able to initiate corrective action in response to the display of out-of-tolerance measurements and recheck specific measurements on demand.

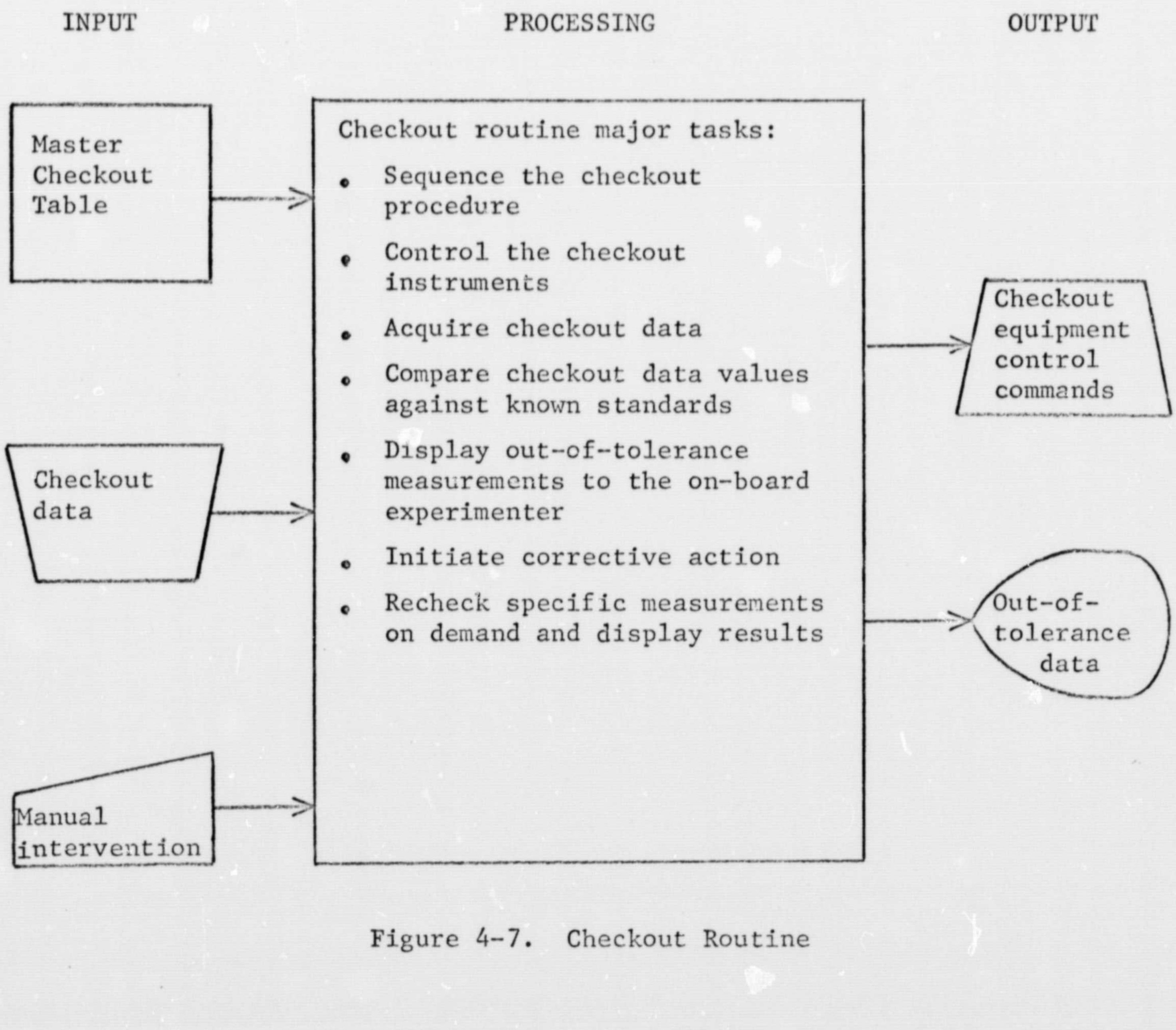


Figure 4-7. Checkout Routine

4.4.4 Calibration

The Calibration routine is required to perform a semi-automatic calibration of the blood gas analyzer, the atmospheric gas analyzer, and the electrocardiograph (see Figure 4-8).

The Calibration routin must provide direct digital control of the calibration components, read the output of the instruments, check the instrument output against pre-specified tolerances, store the calibration data for later reference and allow the on-board experimenter to make adjustments of the instruments to bring them within acceptable limits.

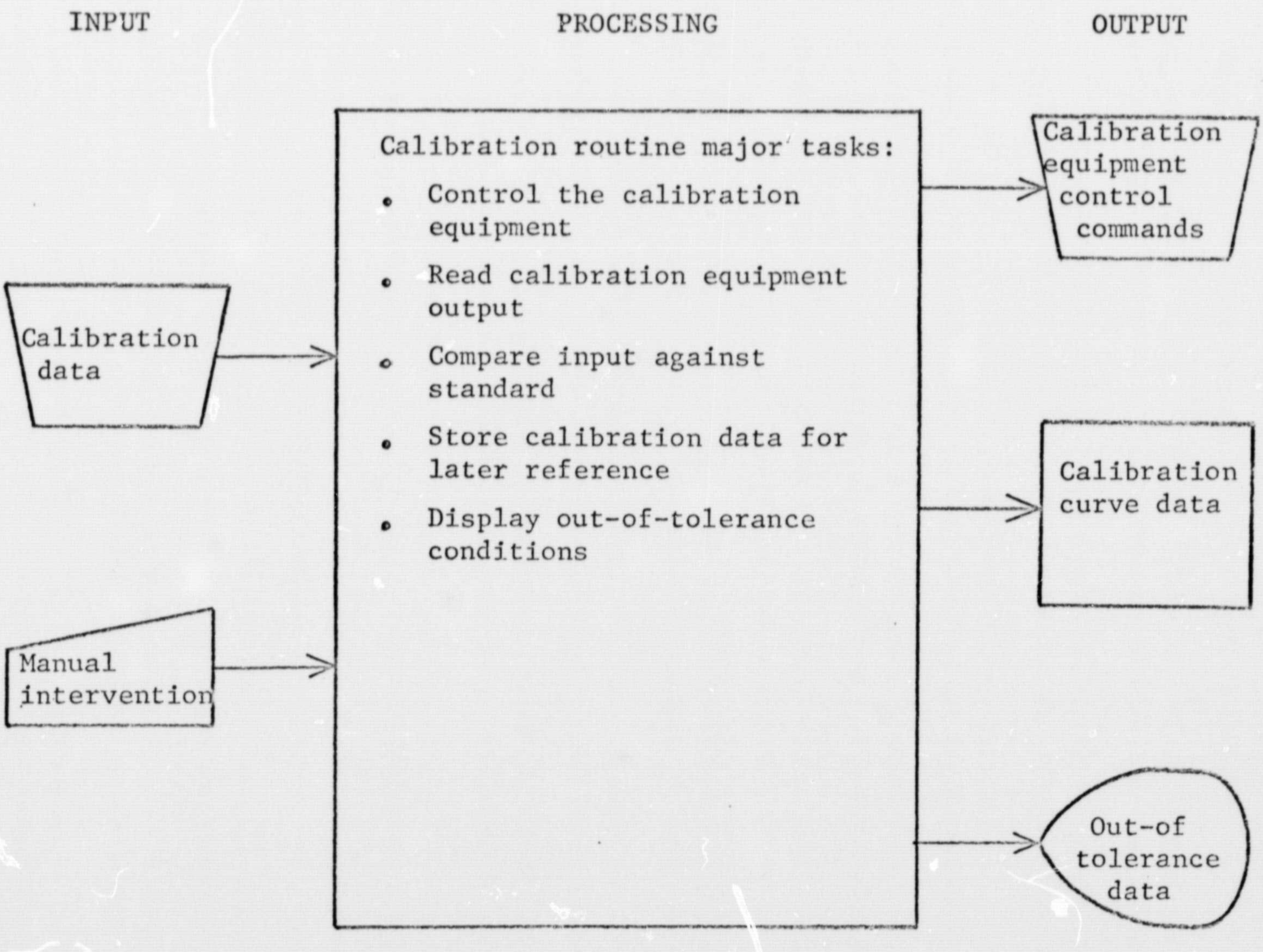


Figure 4-8. Calibration Routine

4.4.5 Primary Instrument Control

The Primary Instrument Control routine is required to provide direct digital control of all primary experiment instruments (see Figure 4-9).

The Primary Instrument Control routine must control a stepping motor and valve system to extract a blood sample from each rat for blood gas content analysis, control a stepping motor and valve system associated with the atmospheric gas analyzer to take samples of the breathing mixture, control a series of valves to measure aortic and ventricular blood pressure and control a stepping motor and valve system to inject saline into the rat's heart to determine cardiac output.

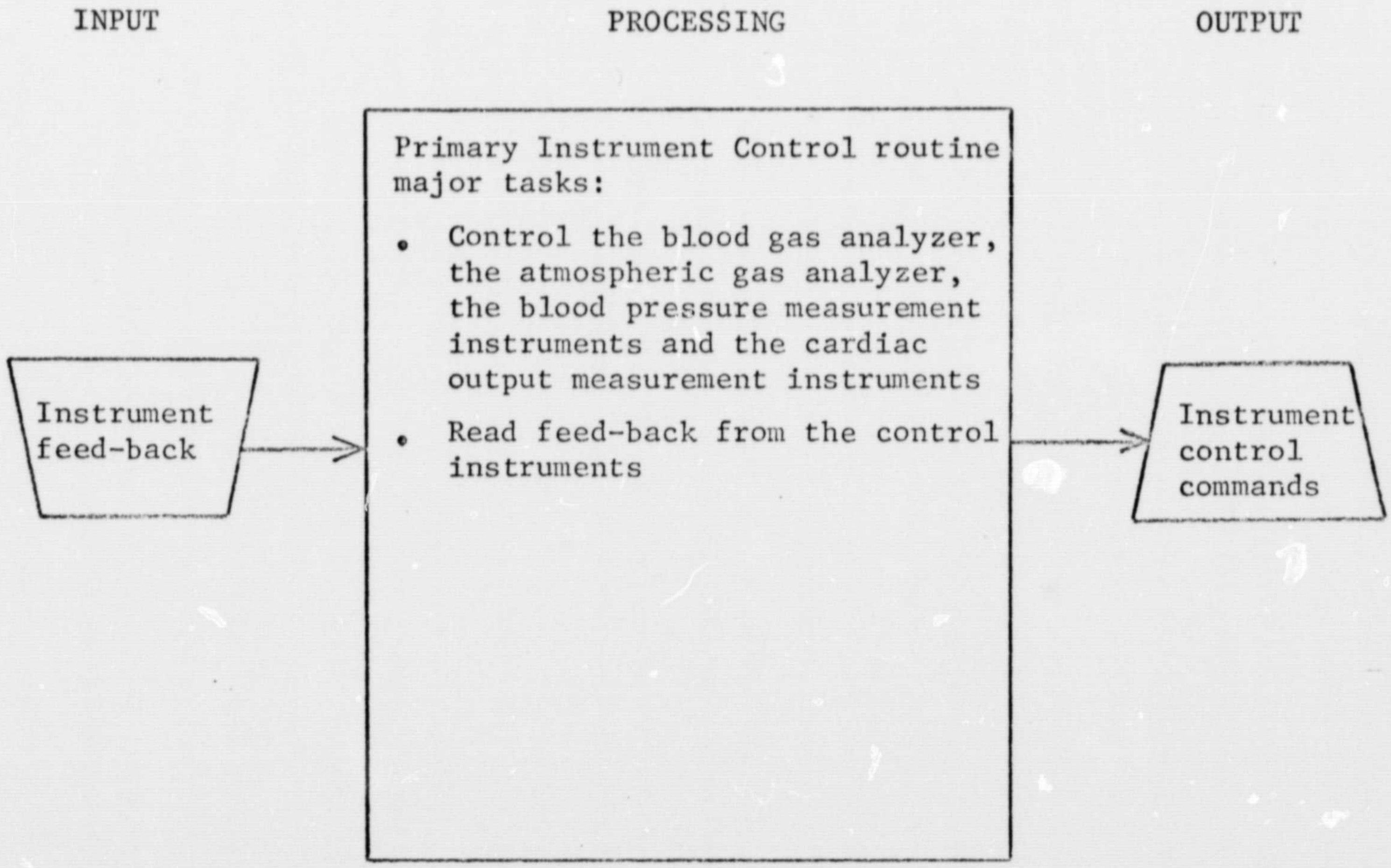


Figure 4-9. Primary Instrument Control Routine

4.4.6 Primary Data Acquisition

The Primary Data Acquisition routine is required to acquire data from the primary experiment instruments (see Figure 4-10).

The Primary Data Acquisition routine must read the output of intra-ventricular EKG measured as a voltage potential between the saline columns of the two cannulas, measure the ventricular and aortic blood pressure through the pressure transducers on each of the two cannulas, read the gas content of the venous and aortic blood through the blood gas analyzer, measure deep body temperature from a thermistor implanted in the aorta and read the output of the atmospheric gas analyzer. All data must be identified and temporarily stored for later analysis.

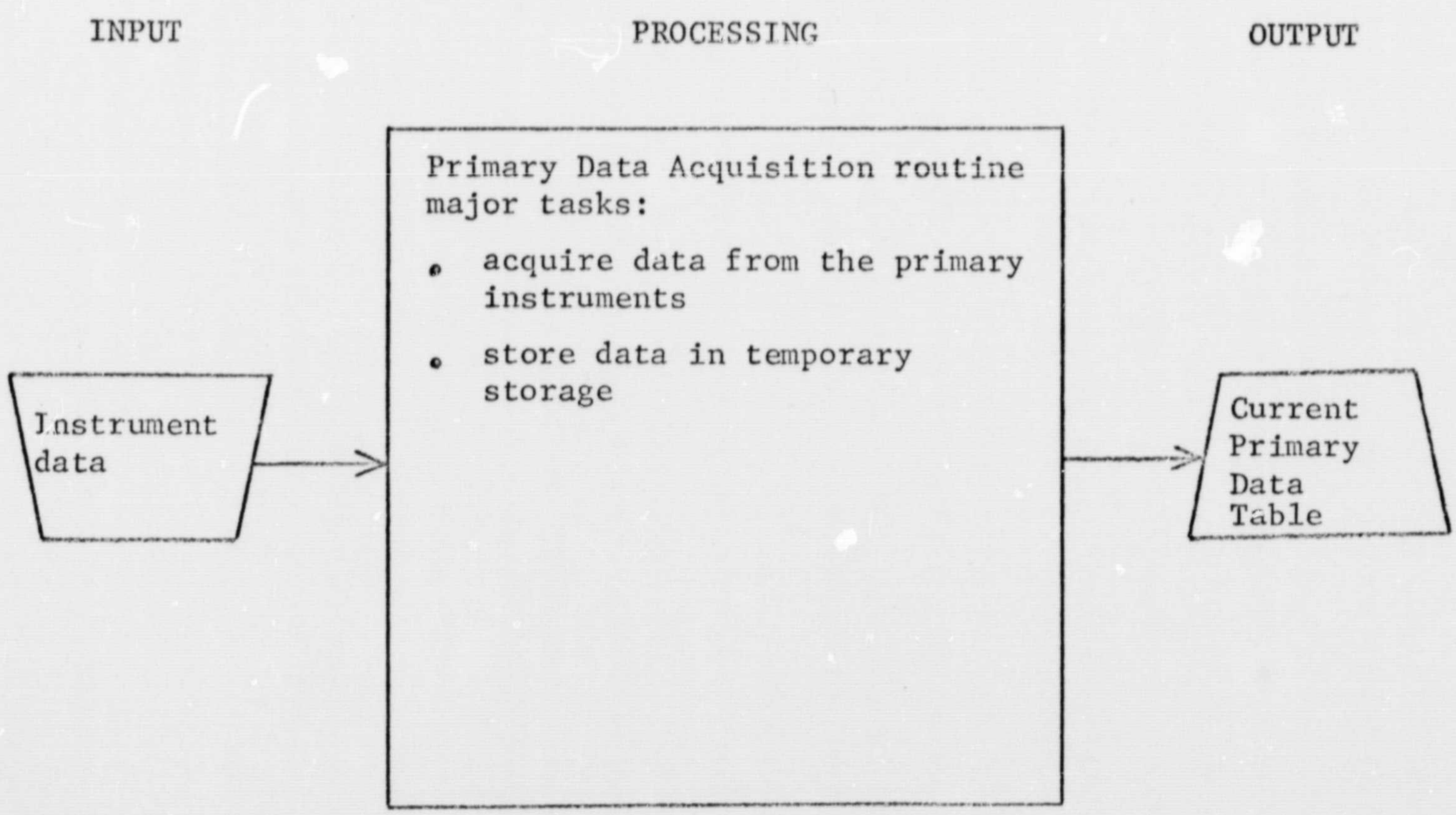


Figure 4-10. Primary Data Acquisition Routine

4.4.7 Primary Data Analysis

A Primary Data Analysis routine is required for on-board analysis of experiment data (see Figure 4-11).

The Primary Data Analysis routine must analyze the EKG wave form to determine heart rate as a function of the QRS interval. Continuous monitoring of the EKG for a period of approximately two minutes will provide an adequate number of time intervals between wave peaks to calculate an average heart rate.

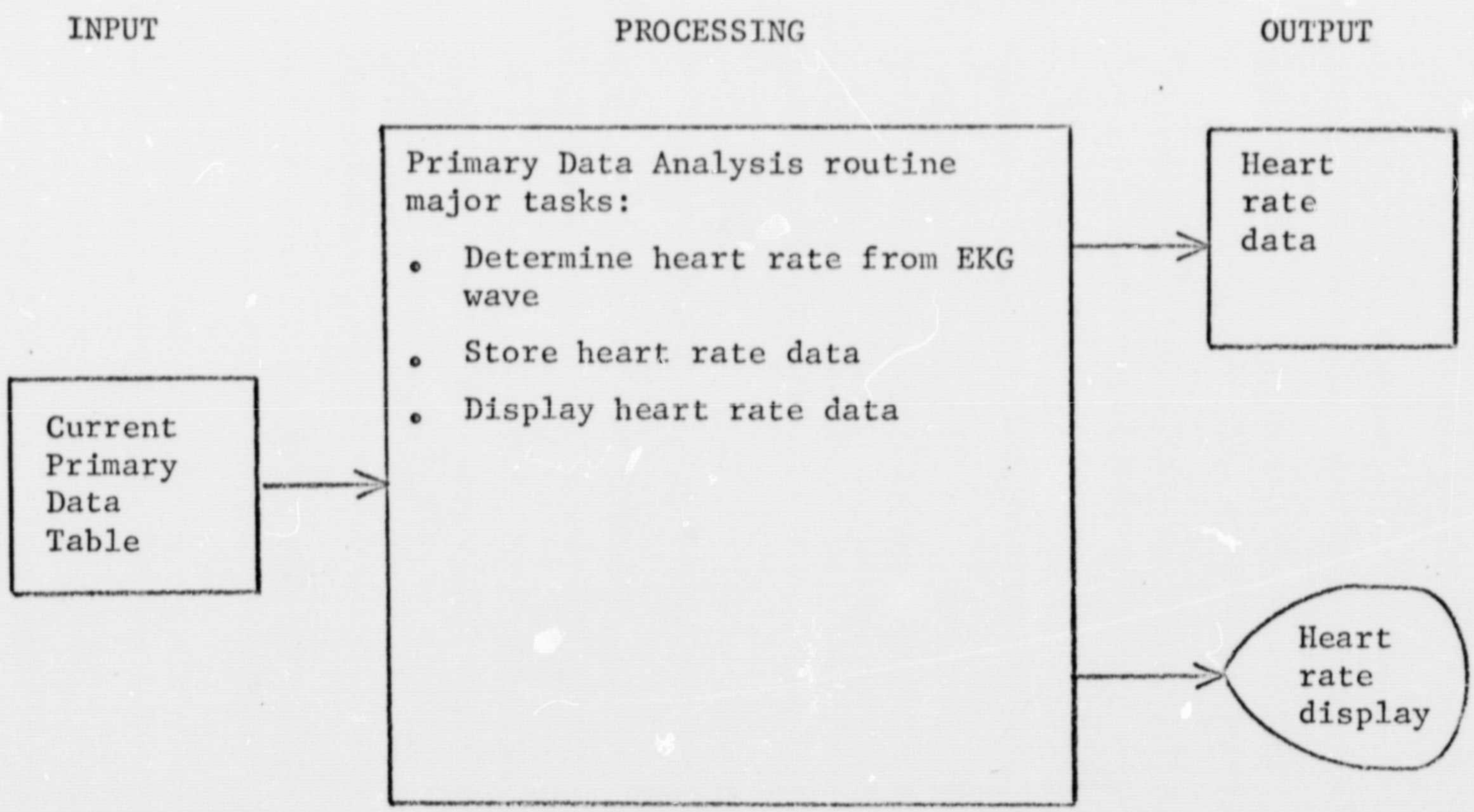


Figure 4-11. Primary Data Analysis Routine

4.4.8 Secondary Data Acquisition

A Secondary Data Acquisition routine is required to monitor all experiment support instruments (see Figure 4-12).

The Secondary Data Acquisition routine must continuously sample vibration, acoustic noise, acceleration and radiation in the vicinity of the rat cages and periodically monitor cage temperature, relative humidity, flow rate and lighting. Data values must be checked to determine if they are within tolerance. In-tolerance values are eliminated. An alarm is generated to indicate out-of-tolerance conditions. Emergency routines to correct specific out-of-tolerance conditions may be initiated automatically or at the request of the on-board experimenter.

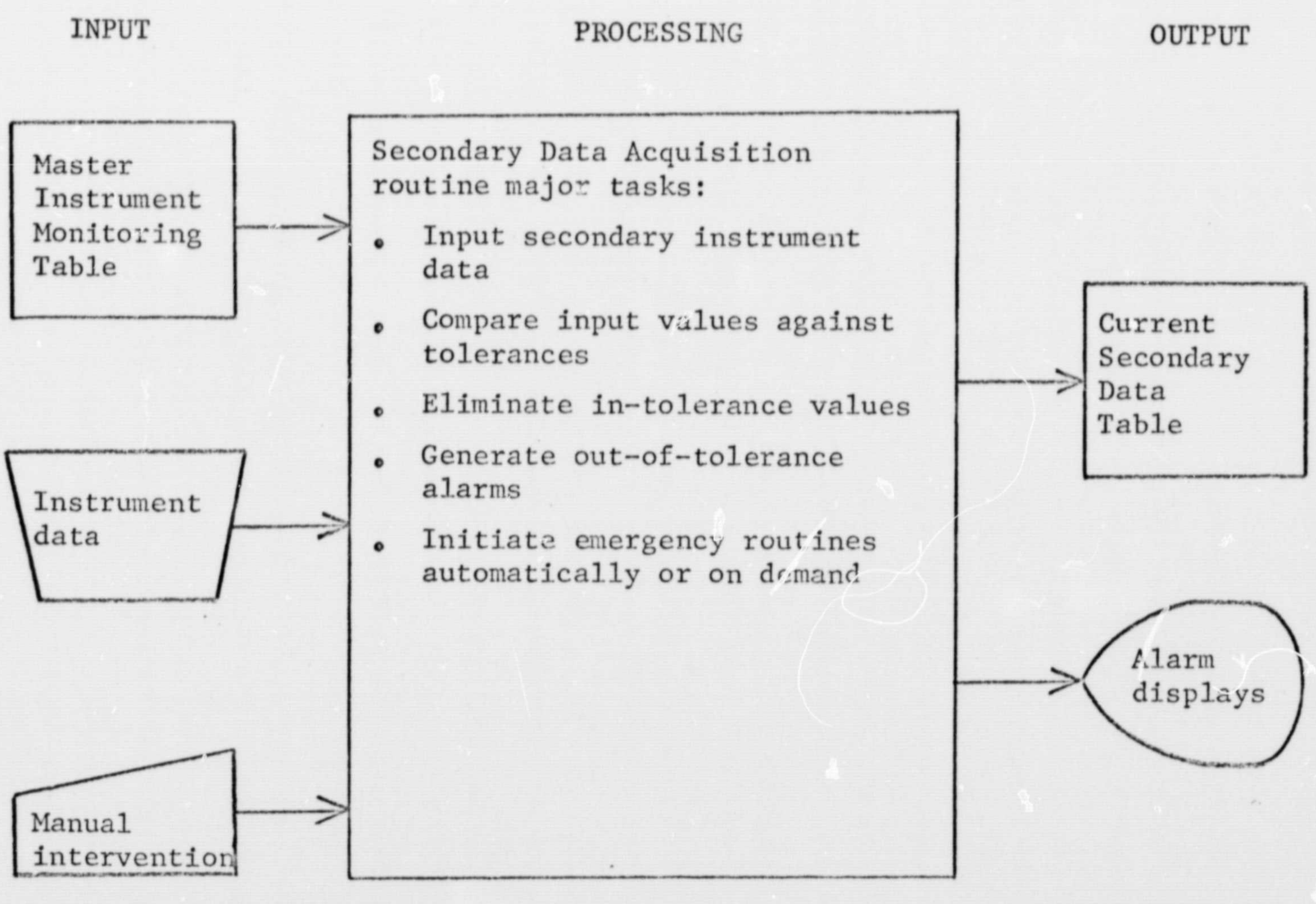


Figure 4-12. Secondary Data Acquisition Routine

4.4.9 Data Reduction

A Data Reduction routine is required to significantly reduce the volume of data generated by this experiment (see Figure 4-13).

The Data Reduction routine must eliminate redundant data, compress the remaining data by various compression techniques and format the resulting data for storage.

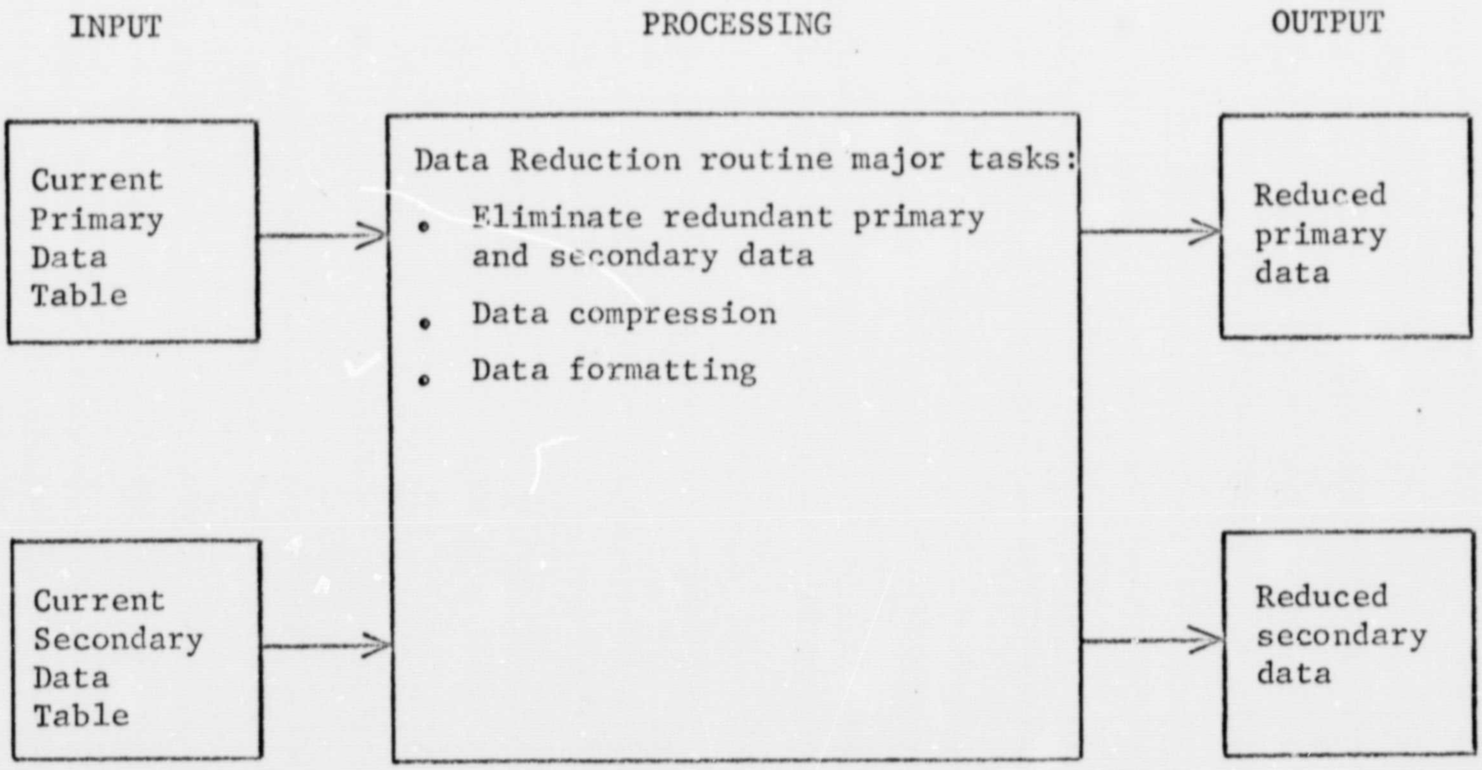


Figure 4-13. Data Reduction Routine

4.4.10 Data Storage and Transmission

A Data Storage and Transmission routine is required to format, store and transmit experiment data (see Figure 4-14).

The Data Storage and Transmission routine must store selected primary data on retrievable mass storage devices for the duration of the experiment, format the primary data for transmission to the ground and store reduced secondary data on portable, write-only storage media for delivery to ground via the Space Shuttle.

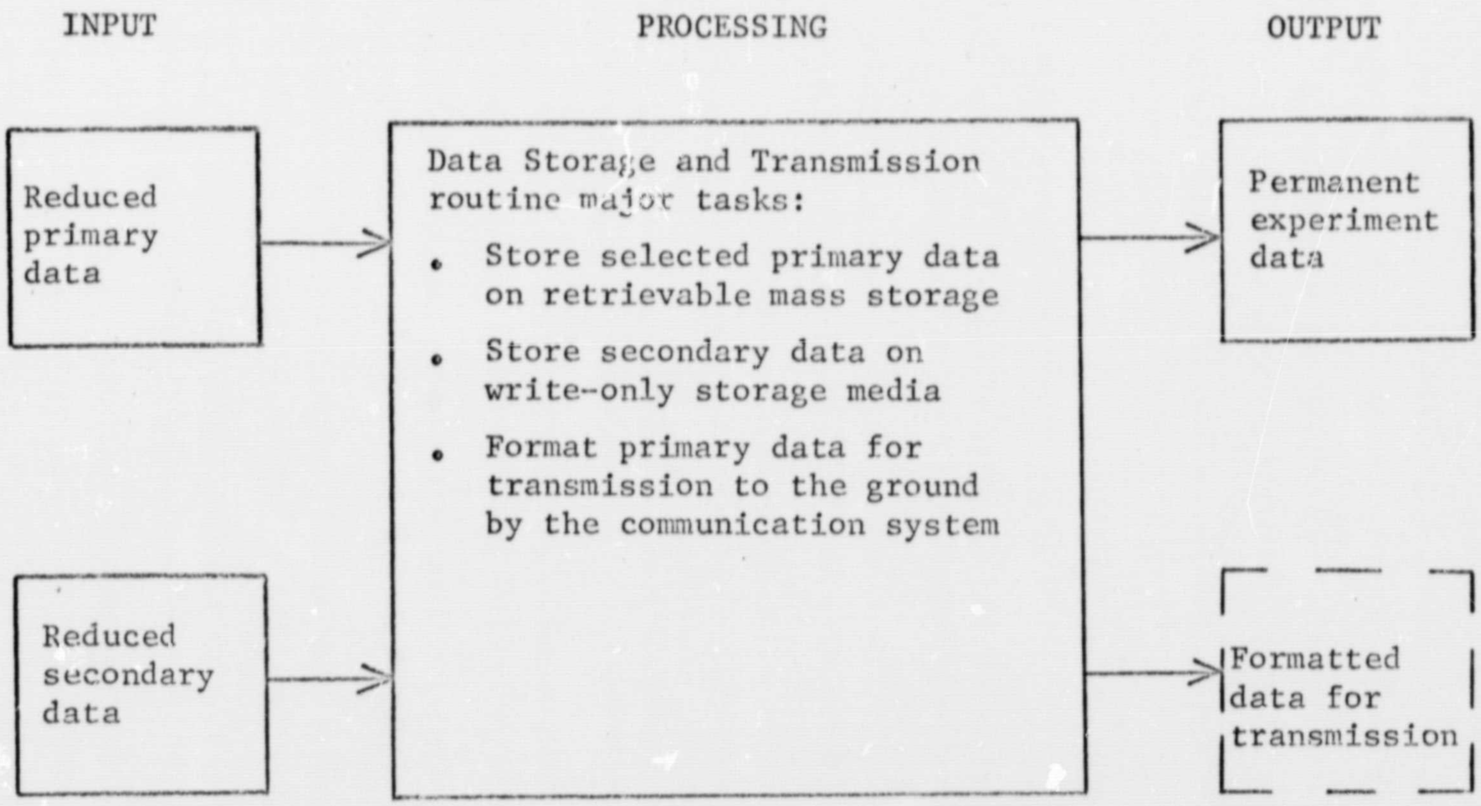


Figure 4-14. Data Storage and Transmission Routine

4.5 Hardware Requirements

The procedures involved in carrying out the operations outlined in the previous section depend heavily on the ability to operate numerous devices under direct digital control. This can be accomplished by adding a number of hardware items to the required data processing system design for experiment support. The hardware items required for data processing support of the Bio-D experiment have been categorized as follows:

- Data Handling Components
- Sampling and Metering Apparatus
- Blood Gas Analyzer
- EKG Electronics
- Atmospheric Analyzer

4.5.1 Data Handling Components

In order to effectively handle various classes of data resulting from this experiment the following data handling components are required:[20]

- High speed digital multiplexers (mux) which accept a number of high speed digital lines and time-division multiplex (TDM) them onto a single line
- Digital sub-multiplexers (sub-mux) which accept a number of slow speed digital signals and time-division multiplex them onto one of the input lines of the high speed mux
- Data modems which modulate a carrier of proper frequency in such a way as to allow transmission of digital data over the Master Data Link [this assumes that the data link will be frequency-division multiplexed (FDM)]
- Data demodulators which provide digital outputs from a frequency modulated input
- Discrete drivers which provide direct digital control (DDC) of experiment operations from the data link

- Digital de-multiplexers which accept TDM signals and produce a number of individual digital signals
- Signal conditioners capable of conditioning a wide selection of analog signals to a standard level, frequency, and polarity
- Analog to digital (A/D) converters
- Digital to analog (D/A) converters
- A selection of function generators needed to generate commonly used repetitive waveforms
- A set of standardized data registers and logic elements which can be patched together to perform special purpose logic functions.

Standardization in the design of such devices is highly desirable since it will aid the modification or reconfiguration of the data handling system by the manipulation of modular components. This is a particular benefit to interface control.

4.5.2 Sampling and Metering Apparatus

The apparatus required for the cardiovascular monitoring of cannulated rats is a highly specialized array of components. The following components are required for automating the experiment sampling and metering operations:

- Blood Pressure Transducers: Transducers must be used in place of a manual readout of blood pressure in order to provide electrical analogs to the data processor.
- Metering Valve: An automatic metering valve is required to inject a precisely metered slug of cold saline for cardiac output monitoring. This valve must be electrically actuated.
- Sampling Valve: A multi-port, two chamber sampling valve is required to connect any desired specimen to the primary instrument assembly. This valve should be electrically actuated and should provide a positive electrical position indication as an output.

- Solenoid Valves: Both two way and three way electrical solenoid valves are required for computer control of the various blood and saline tubes.

- A means should be provided for checkout of key transducers and actuators. Simple relay substitution of a stand by component might be all that is needed for checking a transducer while a talkback limit switch will indicate successful operation of an actuator.

4.5.3 Blood Gas Analyzer

A blood gas analyzer, capable of automatically measuring the oxygen concentration in a very small sample of rat's blood is required. This analyzer should be accurate to ± 2 percent and capable of providing a reading within 10 seconds of sample injection. An internal calibration capability should be provided as well as both manual and remote control and monitoring capability.

4.5.4 EKG Electronics

Sufficient electronics should be provided to signal condition and filter EKG signals for computer input.[21] The following electronics are required:

- A differential amplifier to boost the low level EKG potential difference existing between the saline columns of the two cannulas to a level suitable for filtering

- Low pass filters to remove unwanted noise from the signal while leaving basic P, QRS and T data unaltered

- Signal conditioners to adjust the filter output to a standard analog input form

- A digitally controllable signal generator to insert various simulated EKG signals into the EKG input lines for calibration purposes.

4.5.5 Atmospheric Analyzer

An analyzer should be provided for automatically determining partial pressure gas composition of exhaled breath. It shall consist of the following:

- Two mass spectrometers for simultaneous measurement of cage inlet and exhaust gases. The analyzers should provide the partial pressure measurement of ten common gases including O_2, N_2, CO_2, and CO. The analyzer should be capable of measuring the percentage of gas in a 10,000:1 dilution to an accuracy of 4 percent or better.[22]
- Piping and valving to allow the withdrawal of gas samples into the spectrometer. This should all be electrically controllable.
- A metering device for injecting calibration mixtures into the analyzer. This should be electrically controllable.

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APPENDIX A

Phase A Contributors

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William B. Chubb MSFC Astrionics Lab	Space Craft Pointing Control
Charles Jones MSFC Astrionics Lab	Space Craft Pointing Control
Max Nein MSFC Missions and Payload Planning Office	Free Flying Module Configurations
Jean Oliver MSFC Missions and Payload Planning Office	Experiment Design (general)
Dr. James Milligan MSFC Space Sciences Lab	Spaceborne astronomy experimentation
Paul Davenport Goddard Space Flight Center	Spacecraft pointing and tracking software

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